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DRYING CHARACTERISTICS OF AEROBICALLY DIGESTED SLUDGE

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San Antonio River Authority
San Antonio, Texas

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FINAL REPORT

OF

DEMONSTRATION PROJECT WPC-182-01-67

SUBMITTED TO THE

DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

BY

THE SAN ANTONIO RIVER AUTHORITY

WATER QUALITY AND SUPPLY DIVISION

430 THREE A LIFE BUILDING

SAN ANTONIO, TEXAS 78205

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By: Clifford W. Randall, Ph. D.
C. Thomas Koch

Date: September 10, 1968

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Details of illustrations in this document may be better studied on microfiche.

BY: Clifford Randall, PhD.
Project Investigator

C Thomas Koch, Project Director

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Drying Characteristics of Aerobically Digested Sludge

Introduction

In recent years, activated sludge plants utilizing aerobic digestion for destruction of waste solids have been increasingly used for small installations (2MGD or less). Such plants are typically of contact stabilization or complete mixing design, do not include primary sedimentation, and excess activated sludge is continuously wasted to an aerobic digestion chamber. The waste activated sludge is retained in the digester for a period of several days during which time a large percentage of the solids are destroyed by endogenous respiration and nonbiodegradable solids accumulate. If satisfactory operation of the plant is to be maintained, sludge must be removed from the digester at regular intervals for ultimate disposal. The most common method of disposal for small installations involves dewatering and drying of the sludge on open-air sand beds. In a typical design of a small waste treatment plant, the digestion compartment constitutes approximately forty per cent of the total volume of the plant, and the sludge drying beds usually require about as much area as the treatment plant itself.

Although the process has seen increasing use, very little effort has been directed toward developing an understanding of the aerobic digestion method for the disposal of waste activated sludge. A particular area of neglect has been the determination of factors related to the dewatering and drying of the sludge wasted from the digester. The lack of knowledge regarding the characteristics of an aerobically digested sludge that will dewater readily and the operating conditions necessary to obtain this sludge, has caused serious problems at numerous installations and has greatly limited the usefulness of the process.

Of about forty waste treatment plants in the San Antonio river basin, twelve ranging in capacity from 0.5 to 2.0 MGD, are attempting to utilize aerobic digestion for the destruction of solids. All of these plants are of the contact

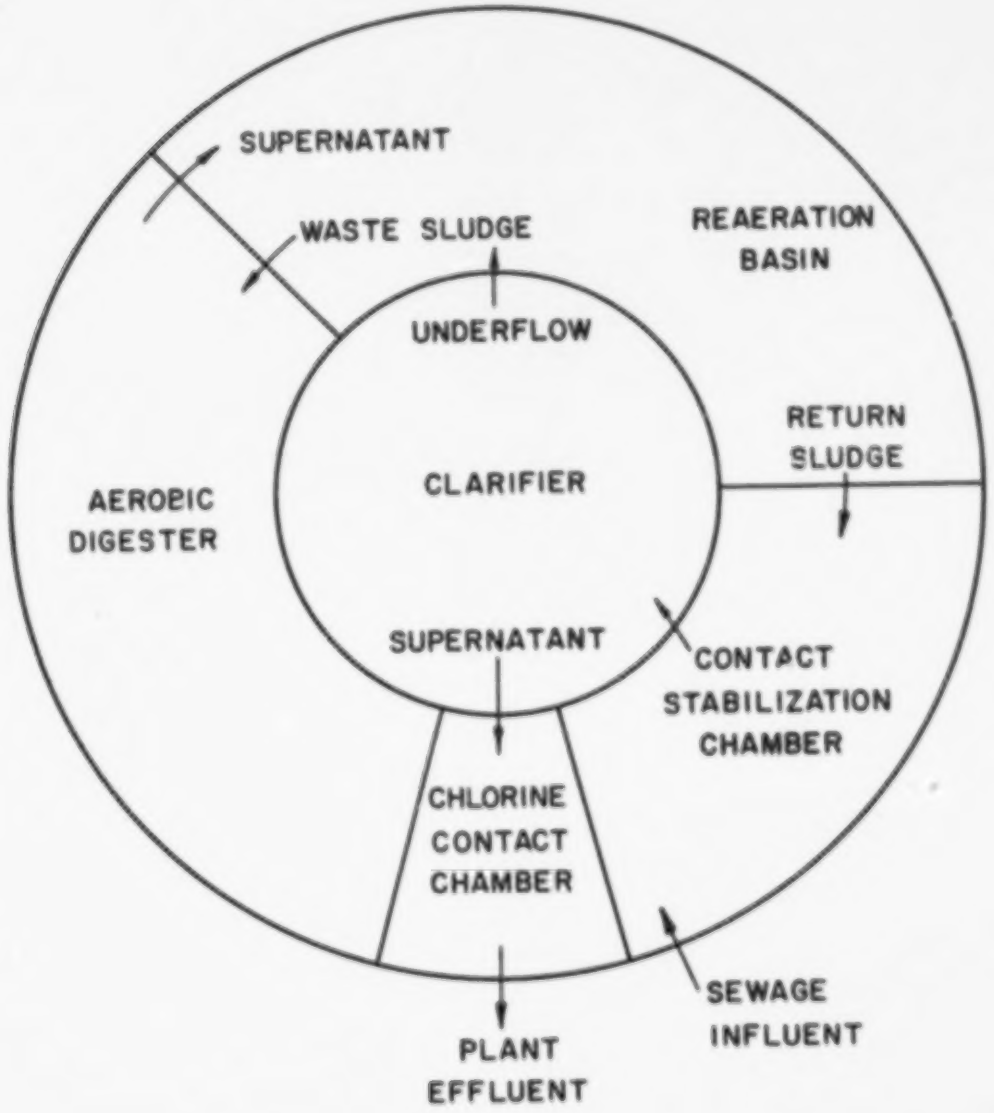


FIG. 1 SCHEMATIC DIAGRAM OF CONTACT STABILIZATION PLANT UTILIZING AEROBIC DIGESTION

stabilization design as diagrammed in Fig. 1. However, nearly all of the plants have been unsuccessful in consistently accomplishing adequate drying rates of the digested sludge. Occasionally the sludge has dried readily when applied to a drying bed but, more typically, the sludge has dewatered very poorly, particularly in depths of twelve inches or more, and the drying beds have been tied-up for long period of time resulting in excessive solids build-up in the plant. However successful drying has been occasionally accomplished.

The principal objective of this project was to determine how an aerobic digester should be operated so that maximum drying rates of the waste sludge on open-air beds can be realized. Particular emphasis was placed on evaluating the primary factors that affect dewatering of aerobically digested sludge and on gaining insight into how the drying rate of a sludge can be predicted. An effort was made to correlate the biological and chemical characteristics of the digester mixed liquor and supernatant to dewatering results. As a secondary objective, digester supernatant and sludge bed filtrate were analyzed to determine how return flow to the treatment process would increase loading. An additional objective was to evaluate the usefulness of two types of sludge bed underdrain design.

Facilities and Procedures

The experimentation for this project took place at the San Antonio River Authority's Salatrillo Creek waste treatment facility, an 0.5 MGD capacity contact stabilization plant with aerobic digestion (Fig. 2). This plant is equipped with a unique valving arrangement which enables any compartment to be drained into any of four special pilot tanks for isolated studies. The pilot digester tanks (Fig. 3) each had a capacity of 1000 gallons and a diameter of about five feet. Five sampling cocks were located vertically on each tank one foot apart and a drain was located at the bottom so that sludge or supernatant

FIG. 2 SALATRILLO CREEK WASTE TREATMENT PLANT

FIG. 3 PILOT DIGESTER TANKS

samples could be removed from any level. Although the capacity of the Salatrillo plant is 0.5 MGD, the actual flow during the time of the study was only 50,000 gallons per day. As a result, complete mixing conditions existed in the plant and the chemical and biological condition of the sludge was the same in each compartment with the exception of the aerobic digester. The sludge was extremely well digested when wasted from the digester and was observed to have excellent dewatering properties.

Twelve model-size sand drying beds, each with a surface area of one-square foot, were constructed and used for experimental purposes (Fig. 4). The beds were portable and were fit into a specially constructed table so that filtrate could be collected in a twenty liter container. Each model bed contained one inch of gravel, three inches of sand, and over eight inches of freeboard. The gravel was supported on a screen and the entire bed drained into a built-on funnel. The Salatrillo Plant was also equipped with four large drying beds of two construction types (Fig. 5). Two of the beds were of typical sand bed construction whereby the filtrate first drains through a sand and gravel bed to an underdrain system. The other two beds were constructed with impervious, concrete bottoms except for a narrow oblong center drain consisting of sand and gravel overlying and underdrain system. With this system, the filtrate must flow laterally to the center drain where it is collected.

The first objective of the experimental work was to define the properties and characteristics of a sludge that could be readily dewatered when applied to an open-air drying bed. Sludge from the Salatrillo Plant was studied and evaluated for this purpose and was used throughout the remainder of the study as a standard sludge to which all other sludges were compared. Mixed liquor was drained from the plant to the pilot tanks where it was aerated for various periods of time in order to study the effects of additional digestion on the

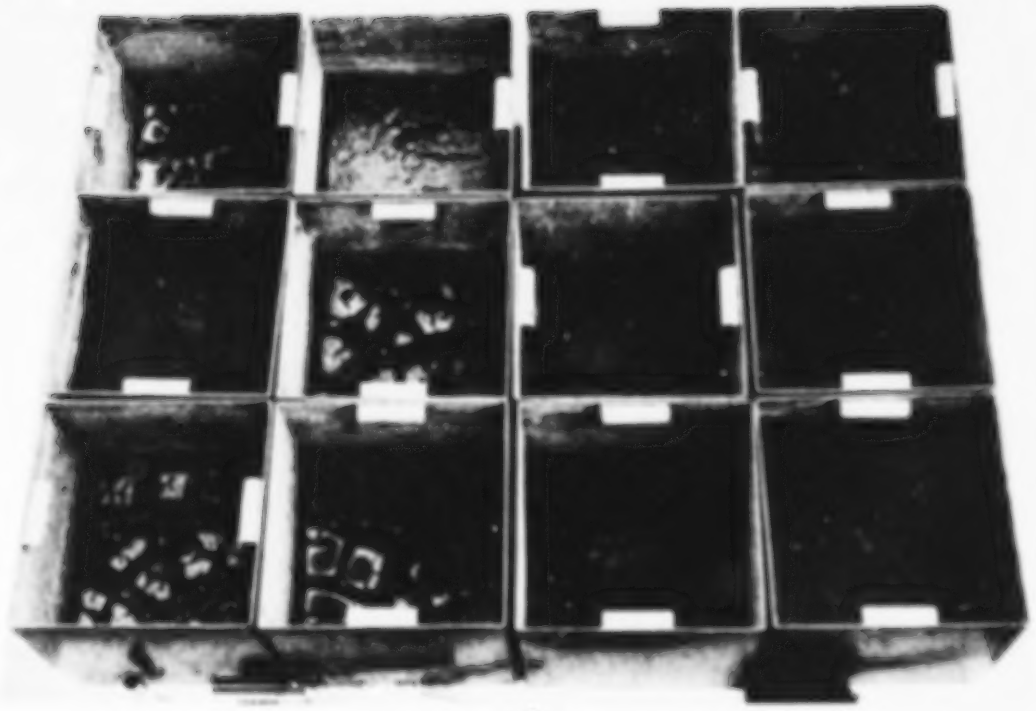


FIG. 4 MODEL SAND DRYING BED SET-UP

FIG. 5 SALATRILLO CREEK SLUDGE DRYING BEDS

sludge and its dewatering rate. The chemical and biological characteristics of the mixed liquor and of the supernatant liquor in the pilot digester were determined nearly every day. Settling curves for each digester were run on a daily basis at the start of each digestion period and at selected intervals, the solids in the pilot tank were permitted to settle and thickened sludge was removed and applied to the model-scale drying beds in depths ranging from four to eight inches. For each run, the filtrate was collected and quantity and rate of drainage was determined. Filtrate samples were occasionally removed from the collecting flask and analyzed. Triplicate samples were used to determine total solids and volatile solids of the thickened sludge for each application. After the free surface water had drained or evaporated from the sludge, core samples penetrating the entire sludge cake were removed each day and analyzed for moisture content. The sludge was typically removed from the drying beds when the moisture content was below 15 per cent. The evaporation rate of the free surface water was noted and observations were made of the change in sludge cake thickness with time. Eighteen drying experiments were performed using Salatrillo sludge applied in depth of either 4, 6, or 8 inches, and with total solids concentrations varying from 7,550 mg/l to 51,000 mg/l. Each sludge and its corresponding solids concentration are listed in Table I in the appendix.

After the Salatrillo digested sludge had been thoroughly studied, sludge was hauled from the digesters of five other contact stabilization plants and placed in the pilot digester tanks for experimental purposes. Most of the sludges were obtained from plants that had experienced considerable difficulty in obtaining adequate dewatering rates of their excess digested sludge. A primary objective of the experiments was to determine if drainage and drying properties could be improved by additional digestion and, if so, what supernatant and mixed liquor condition indicate improvement. The procedure followed during this phase of the project was the same as that used to study the Salatrillo sludge.

Most of the chemical and biological analytical procedures were according to Standard Methods. However, smaller samples were used for several of the chemical tests so that the chemical powder pillows produced by the Hach Chemical Company could be used. All D.O. concentrations including those used for BOD determinations were obtained with silver-lead electrodes. Electrodes were also used for pH determinations.

Weather data was obtained from an adjacent Air Force base and from the U. S. Weather Bureau. This data, including temperature range, relative humidity, and precipitations, is listed in the appendix. In addition, a precipitation gage was maintained at the Salatrillo plant and daily temperature observations were made.

Aeration rates used during the pilot digester studies were varied depending on the nature and concentration of the mixed liquor. The two criteria that were observed were, first, that a minimum dissolved oxygen concentration of 2.0 mg/l be maintained, and second, that adequate mixing be obtained. For most sludges the mixing requirements determined the aeration rate, however, there were a few exceptions. In general, an aeration rate of 0.12 lbs. air/hr./cu/ft. satisfied both criteria.

Salatrillo sludge was used to evaluate the effect of sludge bed underdrain design on dewatering. For this experiment, thickened sludge was pumped from the Salatrillo Plant aerobic digestion chamber to the large scale drying beds where it was applied simultaneously to the sand beds and the concrete-bottomed beds. One bed of each design was filled to a depth of four inches and one of each was filled to a depth of eight inches. The drying rates were determined by observing the reduction of free surface water and by determining the moisture content of the sludge each day.

Daily analysis of the pilot digester contents consisted of determining the

total suspended solids, the volatile suspended solids, the BOD, the D.O., and the pH of mixed liquor. Then the supernatant was analyzed for BOD, pH, D.O., NO_2, NO_3, NH_3, orthophosphate, alkalinity, CO_2, and SO_4. In addition, daily microscopic observations of the sludge were made using magnifications up to 1000 X and photomicrographs were taken for subsequent comparisons. The supernatant was also periodically analyzed for silica, chloride, and dissolved solids content. Several observations of total phosphates were made but the results were very erratic and are not considered to be reliable.

Throughout most of the study the daily average temperature was about 85°F with a high between 95 and 100°F and a low between 80 and 85°F. The relative himidity typically started with a high of 85 to 95% in the early morning hours and decreased to a low of 25 and 35% in the early evening. During the night hours the humidity steadily rose to the morning high. Wind velocity was consistently between 5 and 10 mph.

The results of the first phase of the project demonstrated that it is possible to rapidly dewater aerobically digested activated sludge on open-air sand drying beds. Digested sludge from the Salatrillo Plant, consisting of 97 to 98 per cent water, was consistently dewatered to less than 15 per cent moisture in six to ten days using an applied depth of 8 inches. Depth of 6 and 4 inches dewatered even faster. A typical dewatering curve is shown in Fig. 6.

Additional digestion in the pilot tanks of mixed liquor from the Salatrillo Plant aerobic digester produced no significant change in the draining or drying properties of the sludge. In addition, except for further solids destruction, there was relatively little change in the biological or chemical characteristics of either the mixed liquor or the supernatant with continued aeration. Although a considerable reduction of total and volatile suspended solids could be accomplished with extension of the digestion period, the per cent of volatile

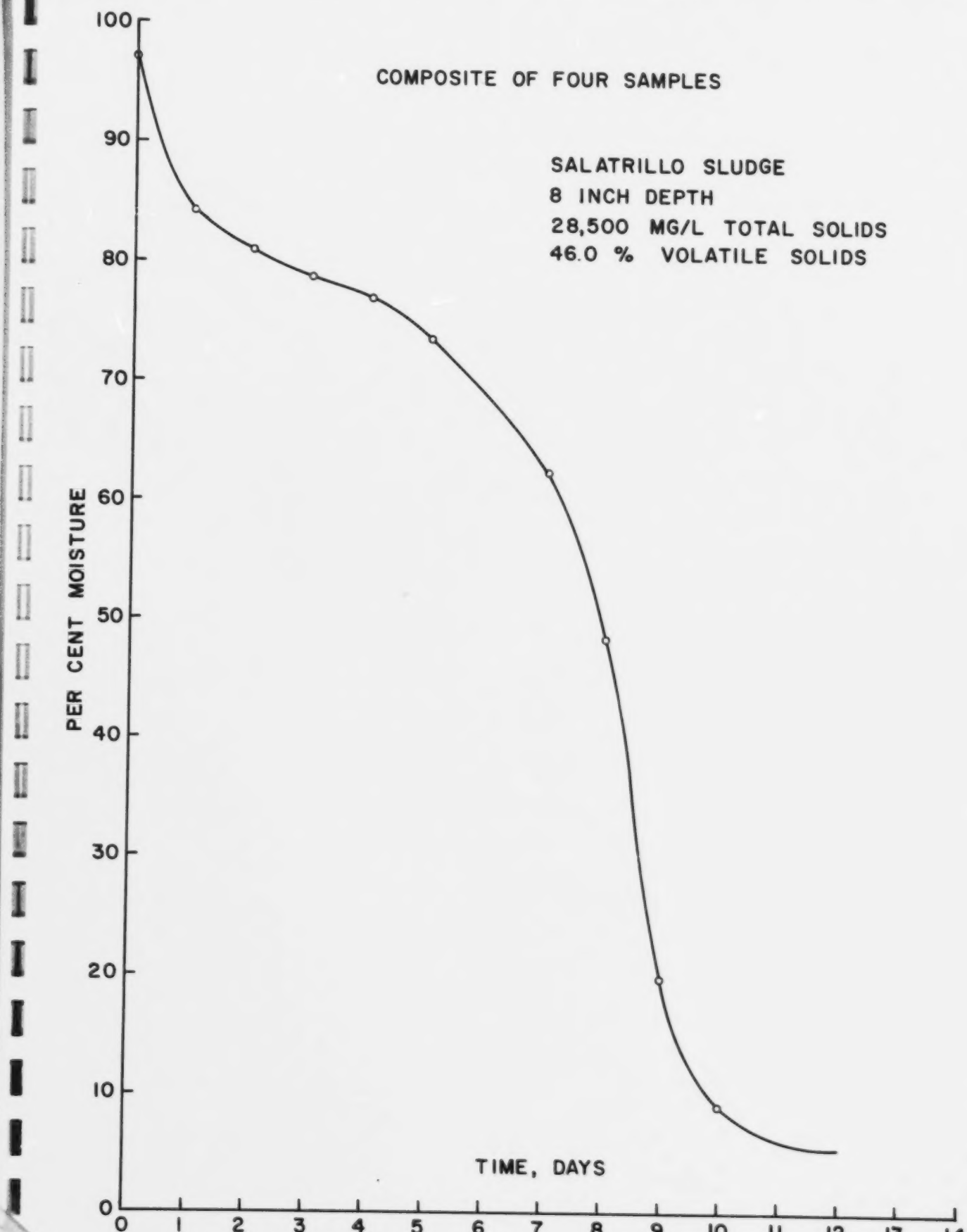


FIG. 6 TYPICAL SLUDGE DEWATERING CURVE

suspended solids to total suspended solids changed very little if any. From the results of the experiments, the Salatrillo sludge was obviously well conditioned for dewatering purposes. An average analysis is shown in Table I.

From Fig. 6 it can be seen that the rate of moisture removal from the sludge changed several times. The rate which occurred the first day was almost entirely due to drainage. The sludge characteristically drained very rapidly when placed on the sand beds. Although the sludge rapidly settled leaving a zone of supernatant above it, for applied depths of up to eight inches a free water surface never existed on the drying beds for more than four hours with the solids concentrations used. The minimum supernatant depth at any time was typically less than 20 per cent of the original applied depth.

The total drainage period was usually eight hours or less for eight inch depths. A typical drainage curve is shown in Fig. 7. The shape of the drainage curve shown in Fig. 7 was typical of all drainage curves obtained regardless of the applied depth or total solids concentration of the sludge. This is illustrated by the composite curve shown in Fig. 8 where time as per cent of total drainage time is plotted against water drained as per cent of total drainage. Of the total water applied with the sludge, 70 to 85 per cent was removed by drainage. A compilation of the various experiments showing per cent total water drained for various applied depths and solids concentrations is shown in Table II. It is interesting to note that, on the average, a larger percentage of water drained from a six inch applied depth than from a four inch applied depth although the difference was slight.

The variation in drainage with applied depth is shown in Fig. 9. From the curves it is obvious that drainage occurred at the same rate regardless of the applied depth until the free water was virtually exhausted. Although this graph is for a total solids concentration of 29,000 mg/l, similar results were obtained for all concentrations.

TABLE I

TYPICAL ANALYSIS OF SALATRILLO AEROBICALLY DIGESTED SLUDGE

TEST	SOURCE	TYPICAL VALUE
PH	MIXED LIQUOR	6.7
VOLATILE MATTER	MIXED LIQUOR	47 PER CENT
BOD	MIXED LIQUOR	300 MG/L
PH	SUPERNATANT	6.8
NO_2	SUPERNATANT	0.02 MG/L
NO_3	SUPERNATANT	30 MG/L
NH_3	SUPERNATANT	0.2 MG/L
PO_4	SUPERNATANT	35 MG/L
ALKALINITY	SUPERNATANT	150 MG/L
CO_2	SUPERNATANT	16 MG/L
SO_4	SUPERNATANT	70 MG/L
BOD	SUPERNATANT	2–5 MG/L
SILICA	SUPERNATANT	26 MG/L
CHLORIDE	SUPERNATANT	65 MG/L
DISSOLVED SOLIDS	SUPERNATANT	800 MG/L

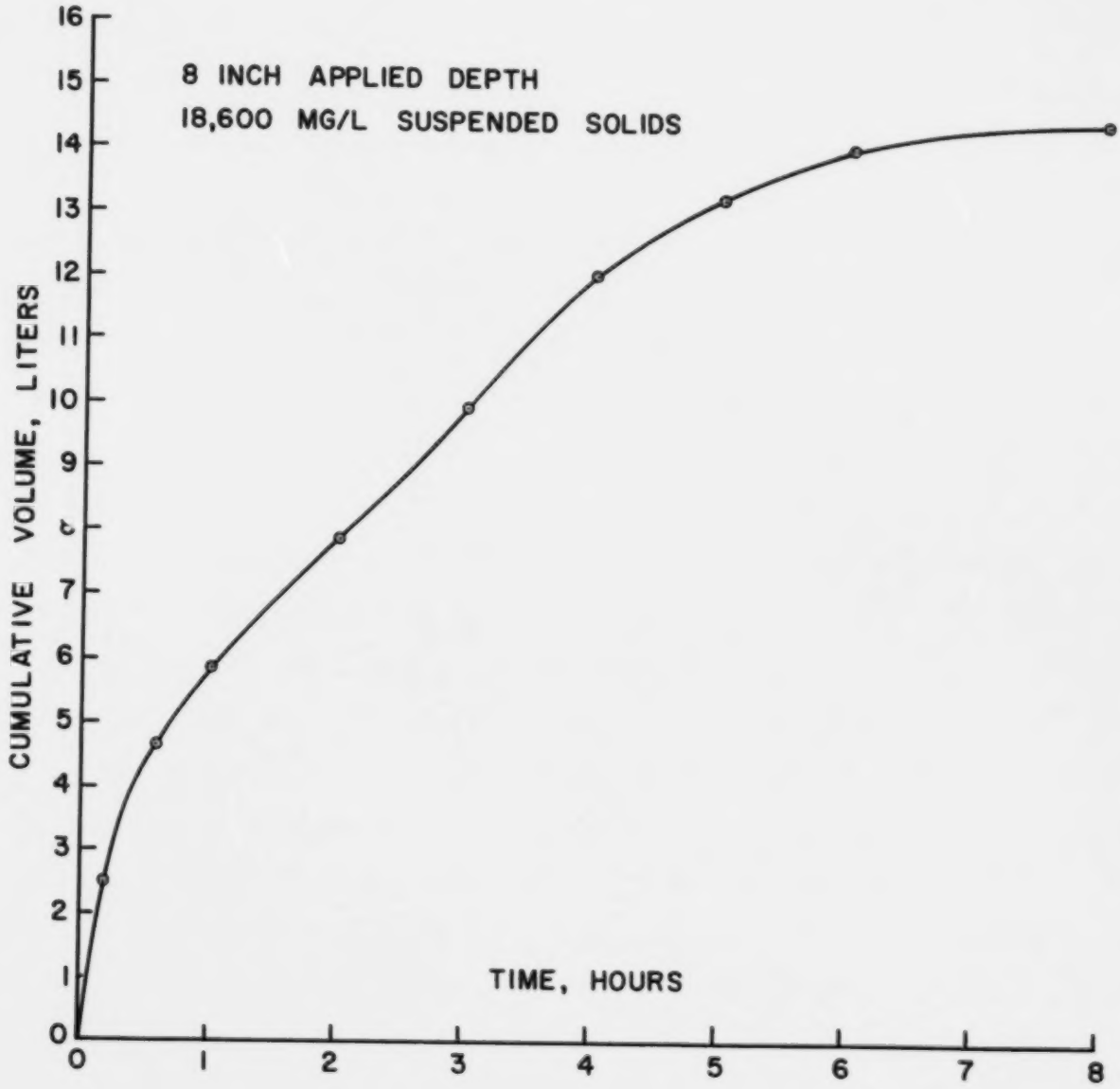


FIG. 7 TYPICAL SLUDGE DRAINAGE CURVE

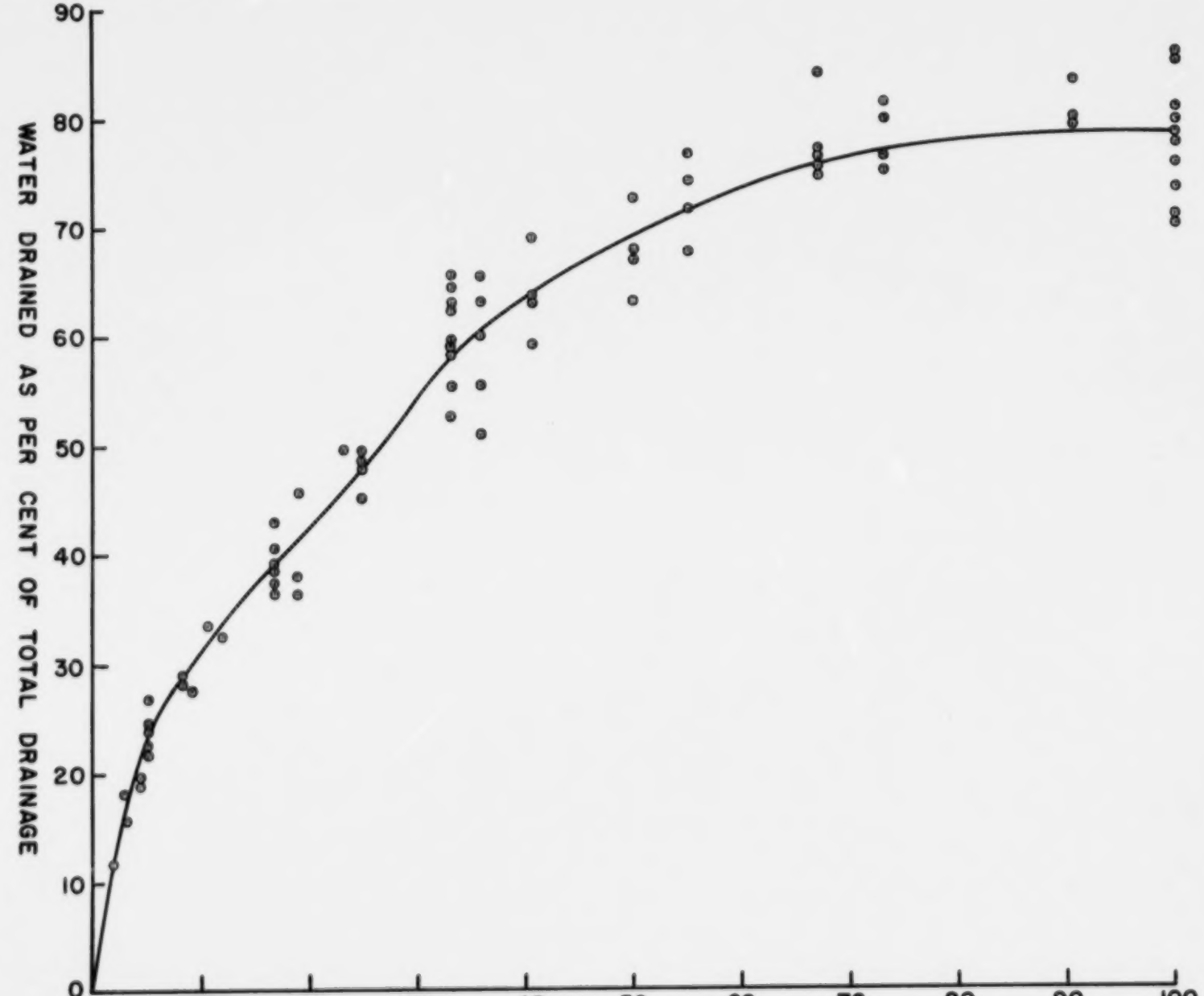


FIG. 8 COMPOSITE SLUDGE DRAINAGE CURVE

TABLE II

SALATRILLO SLUDGE

PER CENT TOTAL WATER DRAINED

SLUDGE SOLIDS CONCENTRATION (MG/L)	SLUDGE DEPTH APPLIED		
	4 INCHES	6 INCHES	8 INCHES
7,550			85.7%
14,600	77.6%		79.3
17,300	86.4	92.2%	79.4
18,600	85.4	85.5	80.3
19,500	85.5		74.5
20,450	80.0	85.0	78.0
21,300			73.6
24,100	78.3		71.0
25,200	74.0		72.0
25,400	72.8	77.8	71.0
28,750	77.7	80.0	73.4
28,800	86.3	85.0	70.5
29,200	78.7	82.1	70.5
29,700	77.5	70.7	70.3
34,000			76.3
38,000	69.0	71.8	67.2
AVERAGE	79.2	80.0	73.4

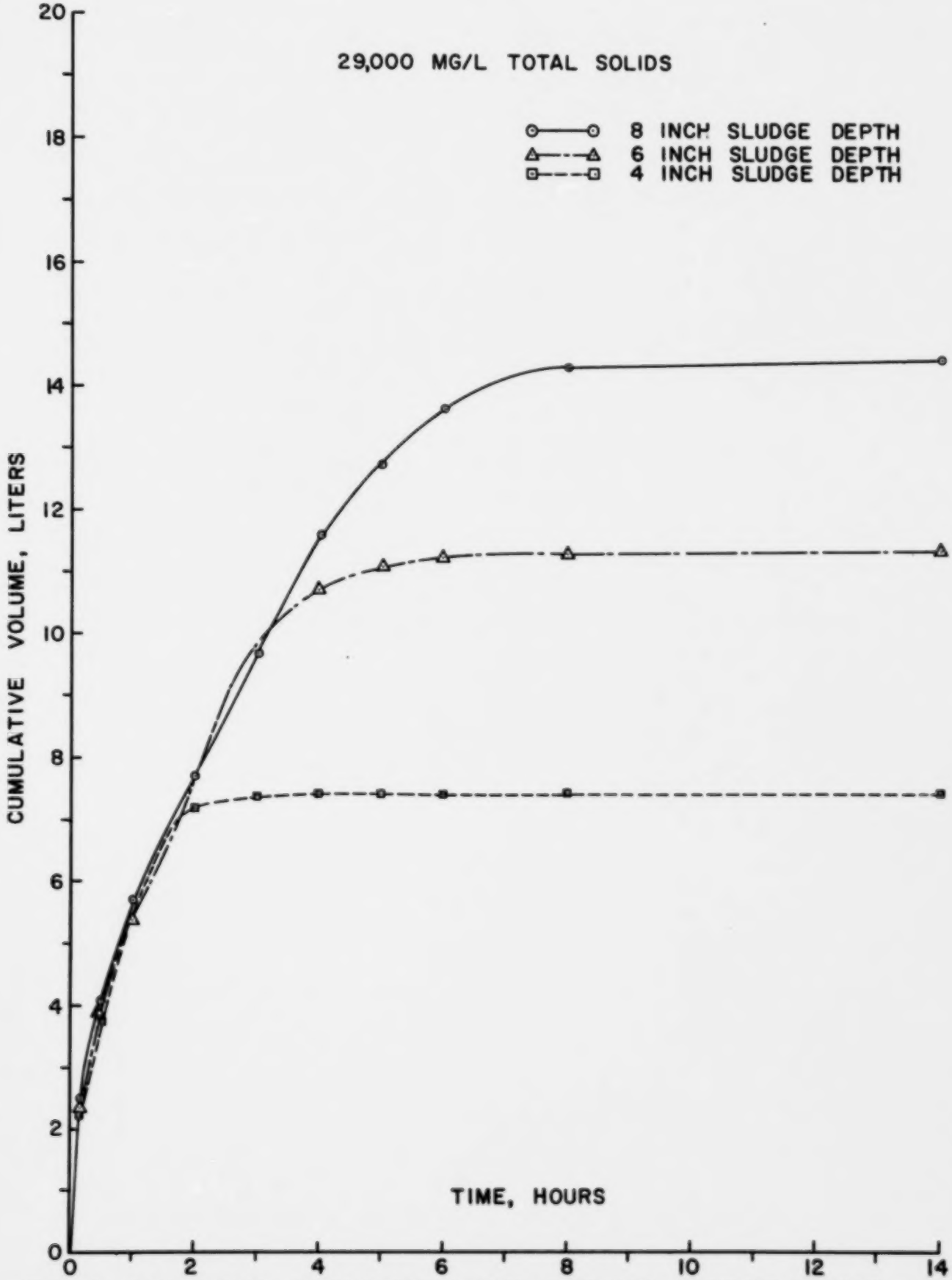


FIG. 9 DRAINAGE VARIATION WITH APPLIED SLUDGE DEPTH

The experimental results did show that drainage rate and per cent of drainable water varies with solids concentration as is illustrated by Fig. 10. However, although it takes twice as long for a sludge with a solids concentration of 38,000 mg/l to drain compared to a concentration of 7,550 mg/l, the period of time involved is insignificant when compared to total drying time. Of more concern is the larger percentage of water retained by the sludge with the high solids concentration which is certain to have a significant effect on subsequent drying time. This effect is shown by Fig. 11.

Of the curves shown in Fig. 11, the 7,550, the 14,600, the 19,500, and the 24,000 mg/l curves represent drying experiments run simultaneously. The experiments represented by the 29,700 and 38,000 mg/l curves were started two days later. During the entire period of these graphed observations weather conditions were very consistent. The 51,000 mg/l curve run was begun three weeks later under more humid conditions. The 7,550 mg/l sludge and the 14,600 mg/l sludge were taken from the same pilot digester. The 19,500 mg/l sludge, the 24,000 mg/l sludge, and the 29,700 mg/l sludge were taken from a second pilot digester whereas the sludge represented by the 38,000 mg/l and 51,000 mg/l curves was taken from a third pilot digester. The basic differences in conditions in the three digesters were the solids concentration maintained and term of digestion. Per cent volatile solids varied by less than 2 per cent among the three basic sludged for all applications.

Fig. 12 illustrates the variation in total dewatering time with applied depth. Although the four inch depth dried two days earlier than the eight inch bed, for a well-conditioned sludge it is obviously more economical to use the larger depth. Salatrillo sludge had no offensive properties with regard to ultimate disposal at a moisture content of 15 per cent and was friable at moisture contents less than 10 per cent A compilation of all dewatering and drainage rates observed are listed in the appendix.

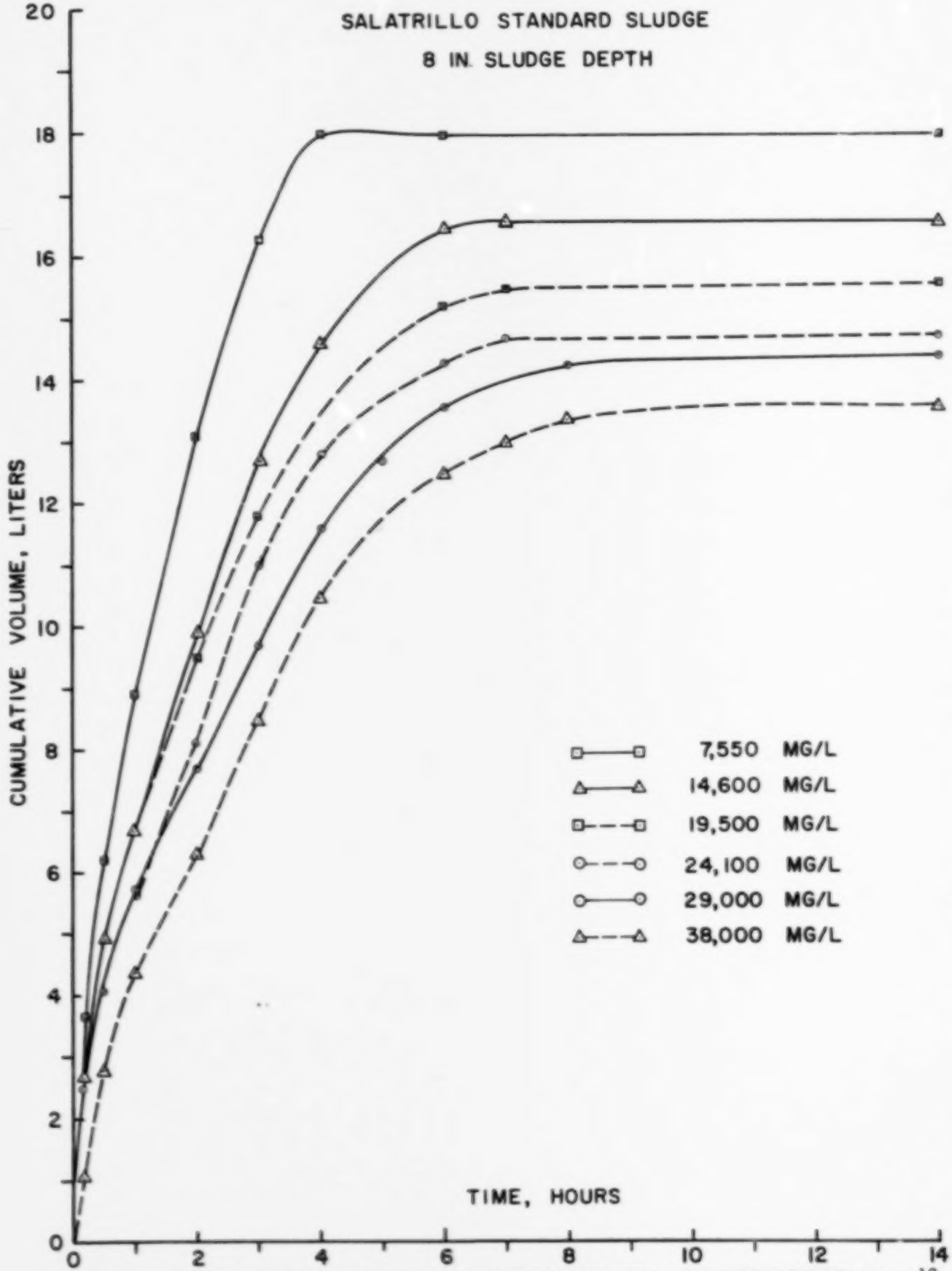


FIG. 10 DRAINAGE VARIATION WITH SOLIDS CONCENTRATION -10

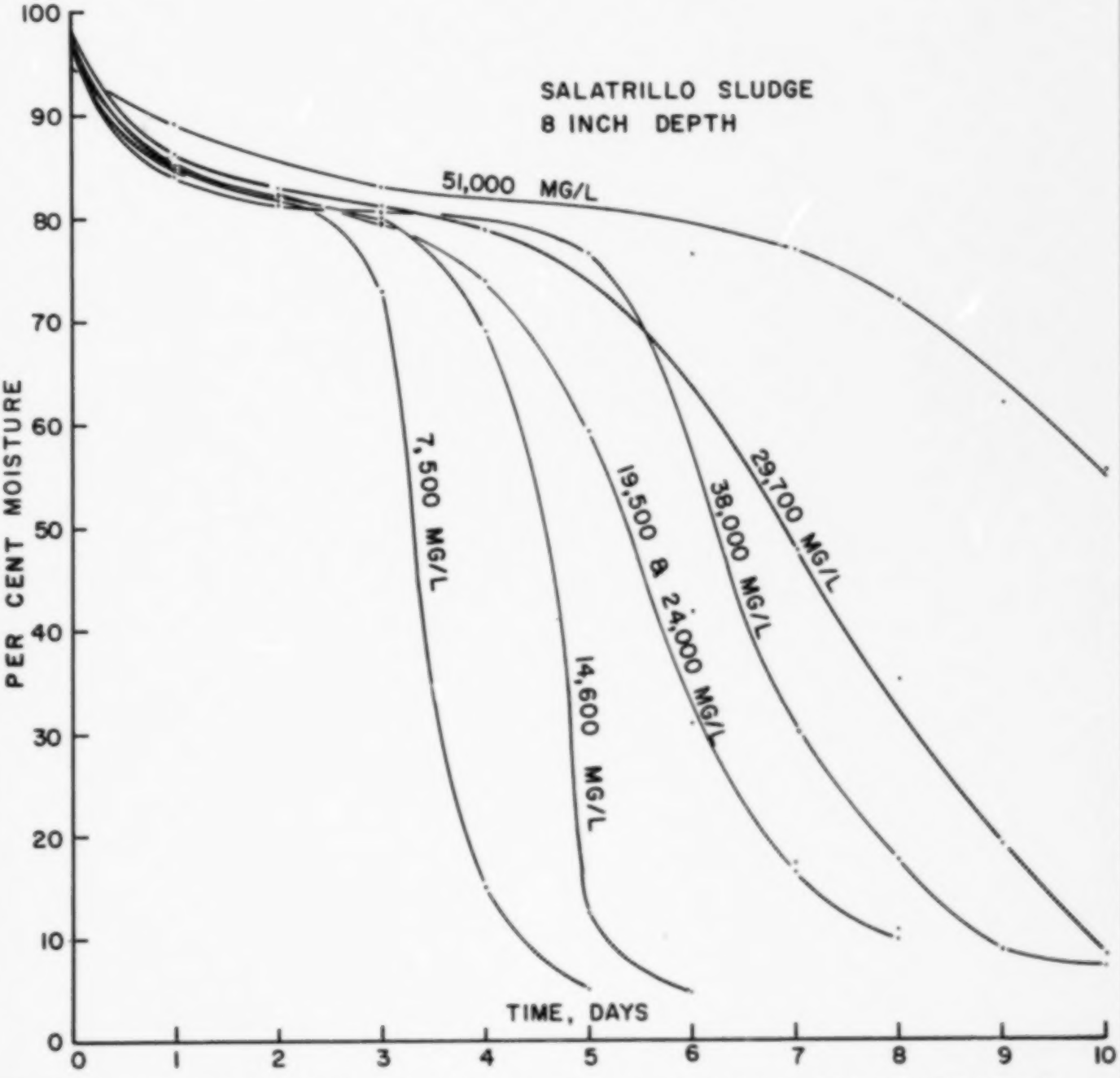


FIG. 11 DEWATERING VARIATION WITH SOLIDS CONCENTRATION

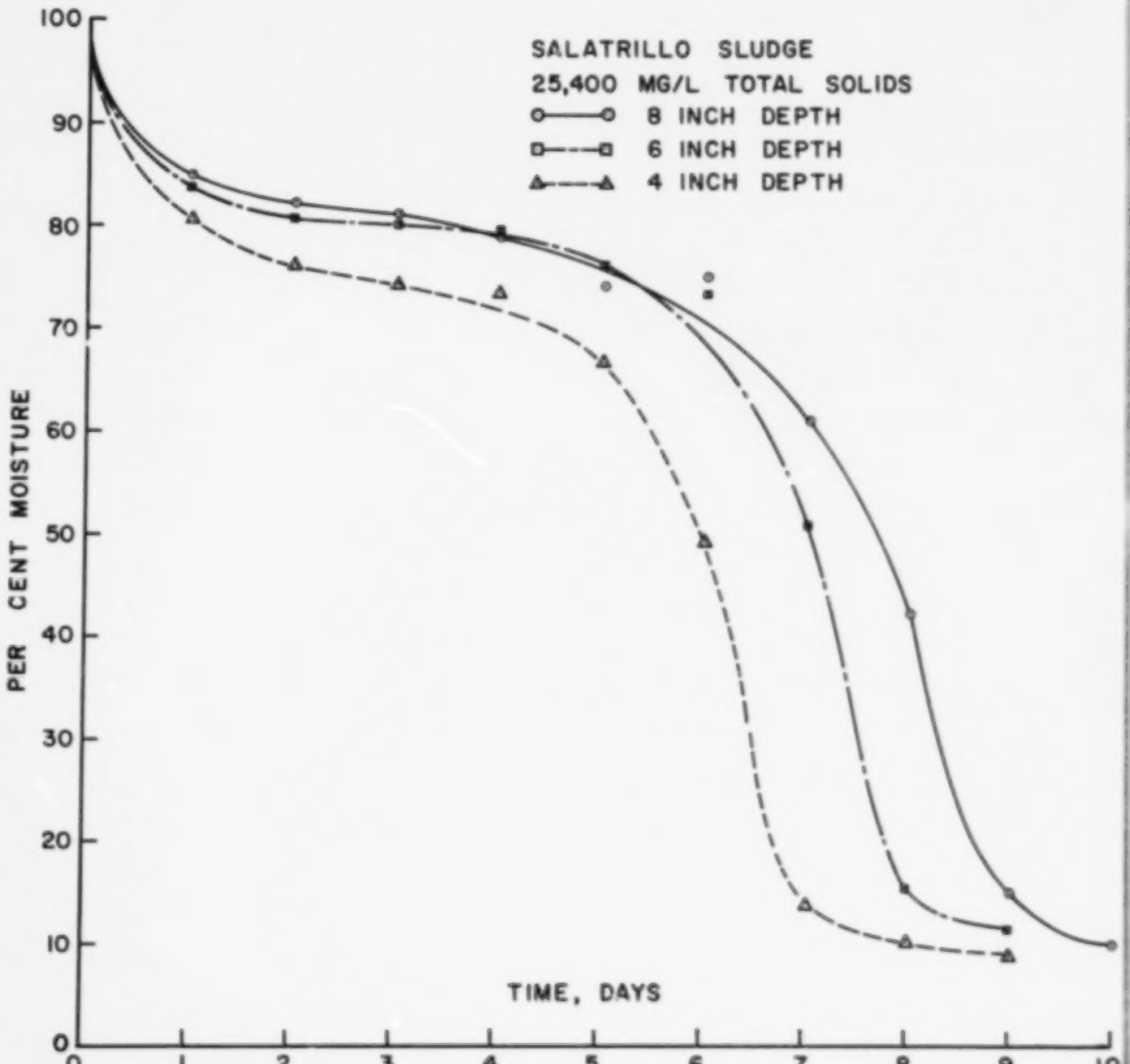


FIG. 12 DEWATERING VARIATION WITH APPLIED DEPTH

The variation in sludge depth with time is shown in Fig. 13. Typically an applied depth of eight inches had been reduced to a total depth of less than an inch when it was ready to be removed from the bed. The final sludge cake thickness obtained for each experiment and its corresponding moisture content are listed in Table III.

Effects of Sludge Bed Design: Since excellent dewatering results had been obtained with Salatrillo sludge on the model drying beds, this sludge was used to evaluate the usefulness of sludge beds designed with an impervious bottom except for an oblong centerdrain. Both 8 inch and 4 inch applied depths were used and the results of this study are shown in Fig. 14. The concentration of the sludge applied to a depth of 8 inches and that applied to a depth of 4 inches was 15,000 and 26,000 mg/l respectively. From this figure it can be seen that sludge applied to the sandbeds dewatered nearly as readily as sludge applied to the model units. The free surface water had drained from the 8 inch applied depth in less than seven hours and the sludge had cracked after eight hours. The 4 inch applied depth had no free surface water after two hours and the sludge cracked after three. By contrast, the sludge applied to a depth of 8 inches on the impervious bed with centerdrain still had a free water layer one inch deep at the outer edge after 10 days. Algae bloomed on the water surface after 5 days. The 4 inch applied depth did somewhat better on a centerdrain bed. The free surface water was gone after 2 days. However, even after 6 days, any cracks in the sludge, with the exception of that over the centerdrain, were filled with water. Consequently, after 7 days the moisture content was still 90 per cent. Unfortunately, the study was terminated by a hurricane after the 8 inch depth and the 4 inch depth had been on the beds 18 days and 7 days respectively. Photographs of the 8 inch applied depths 3 days after application are shown in Figures 15 and 16.

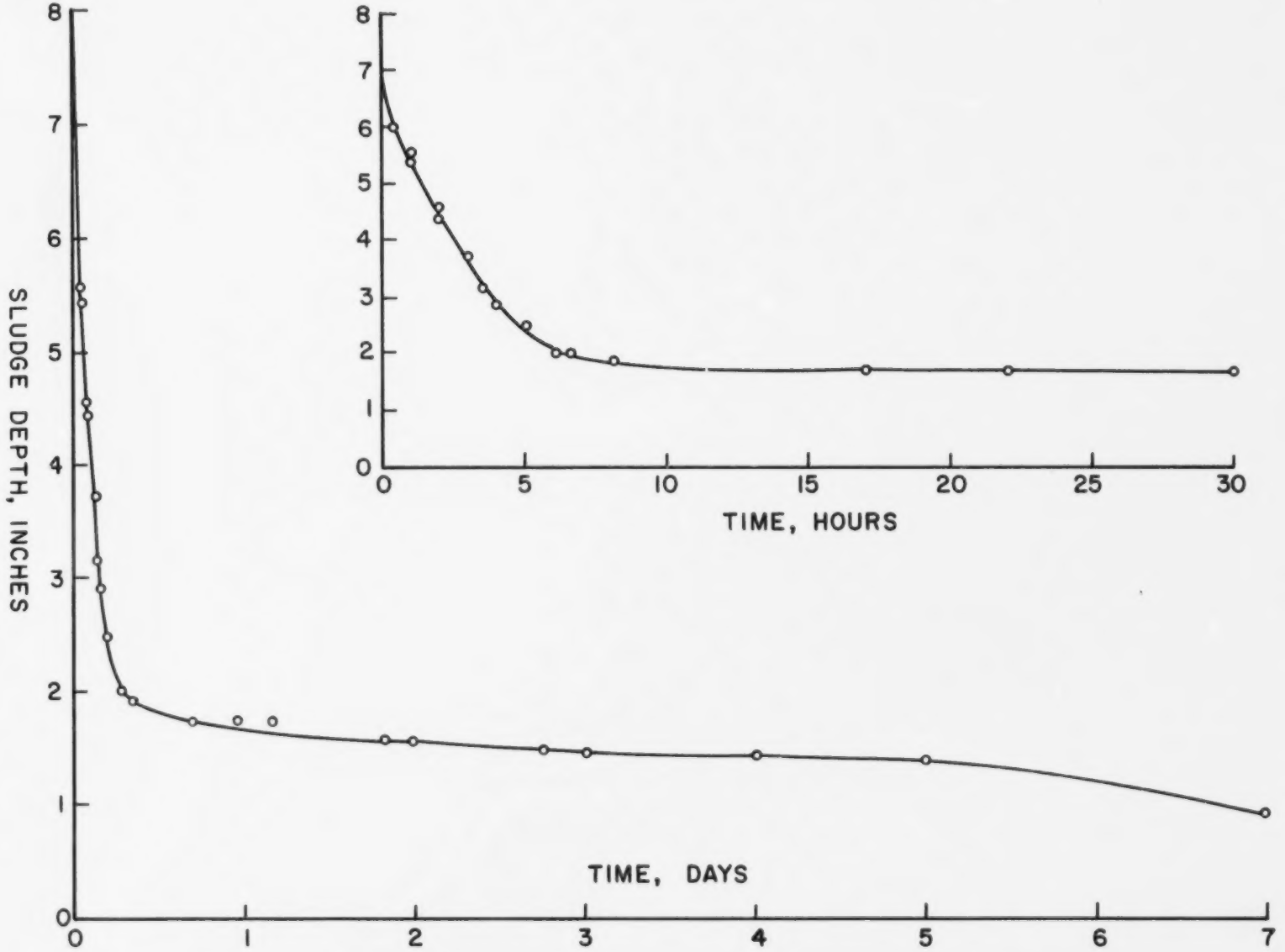


FIG. 13 VARIATION OF SLUDGE DEPTH WITH TIME

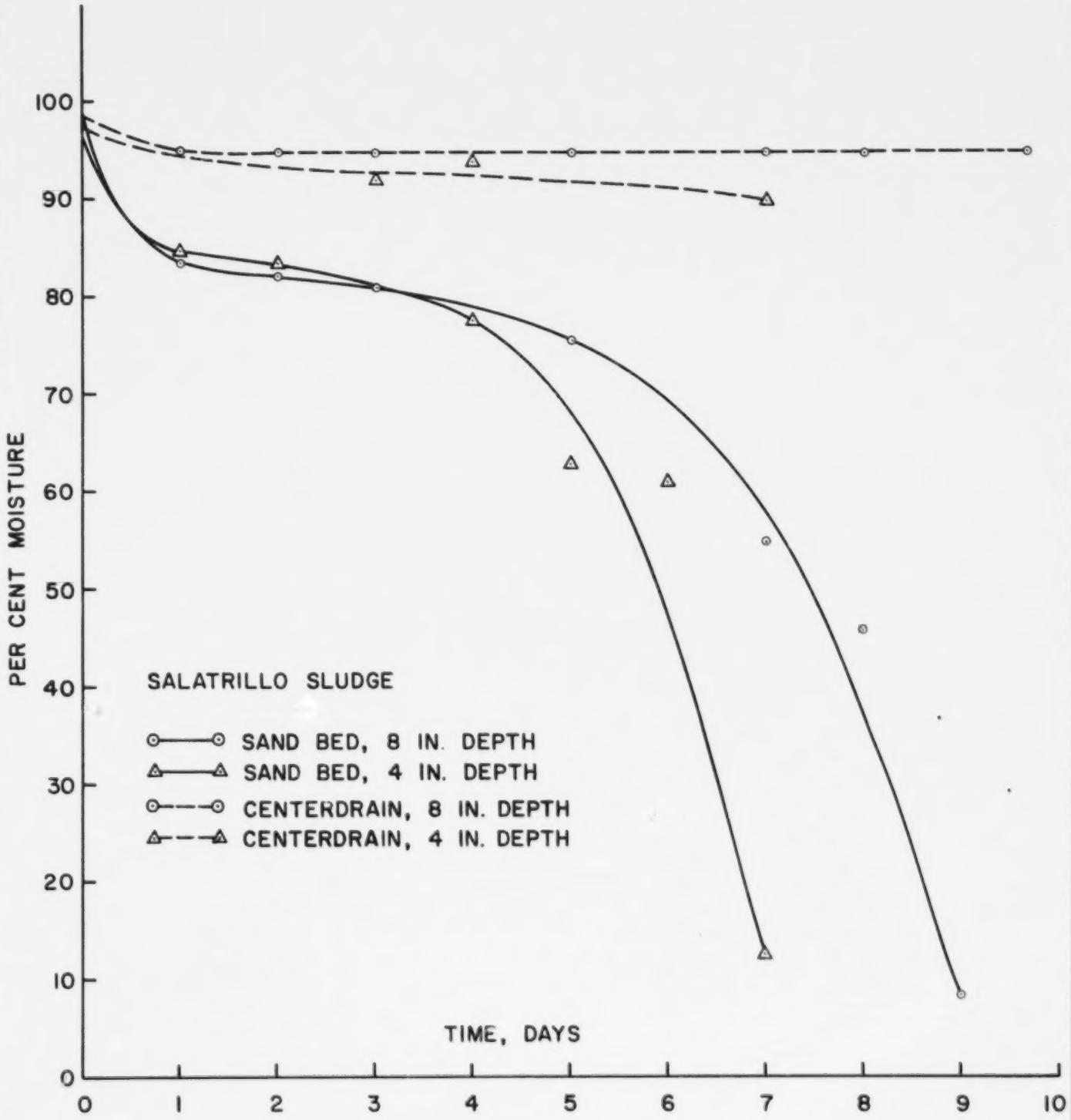


FIG. 14 EFFECT OF UNDERDRAIN DESIGN ON DEWATERING

TABLE III

SALATRILLO SLUDGE

FINAL SLUDGE CAKE THICKNESS

SLUDGE SOLIDS CONCENTRATION (MG/L)	FINAL SLUDGE THICKNESS INCHES APPLIED DEPTH			FINAL MOISTURE CONTENT PER CENT APPLIED DEPTH		
	4 INCHES	6 INCHES	8 INCHES	4 INCHES	6 INCHES	8 INCHES
7,550			0.15			5.0
14,600	0.15		0.40	44		4.5
17,300	0.45	0.60	0.75	9.8	10.1	10.2
18,600	0.45	0.60	0.85	9.4	12.8	12.3
19,500	0.25		0.75	5.0		9.7
20,450	0.45	0.65	0.80	9.5	32.1	25.2
21,300			0.95			24.0
24,100	0.25		0.80	6.1		10.8
25,200	0.45		1.10	3.9		8.4
25,400	0.40	0.75	1.00	9.1	9.1	8.4
25,400	0.40	0.80	1.10	8.7	13.0	12.9
28,750	0.50	0.90	1.10	9.4	9.4	19.5
28,800	0.60	0.90	1.15	9.3	18.9	16.9
29,200	0.50	1.00	2.20	8.8	23.5	30.0
29,700	0.45	0.60	0.80	7.2	10.2	7.5
34,000			1.10			55.5
38,000	0.45	0.65	1.00	7.6	9.3	6.9

FIG. 15 EIGHT INCH DEPTH ON SAND BED AFTER THREE DAYS

FIG. 16 EIGHT INCH DEPTH ON CENTER DRAIN BED AFTER THREE DAYS

COMPARATIVE SLUDGE STUDIES: The various sludges studied during the second phase of the research, along with solids concentration information, are listed in Table IV. The column headed, DAY, refers to the period of additional digestion the sludge had undergone in the pilot digester units before that particular sample was removed for application to the model drying beds. Run number 6 of the experiments with Universal City sludge is not typical of the group. When the sample was taken the unit contained a mixture of 25 per cent Salatrillo sludge and 75 per cent Universal City sludge.

All of the aerobically digested sludges listed in Table IV were obtained from plants treating strictly domestic sewage with the exception of the Universal City sludge. The Universal City plant was treating a flow containing 10 to 15 per cent laundry waste by volume with the remaining portion being domestic sewage. This facility was overloaded, had a considerable odor problem, and was producing a poor effluent as measured by BOD and suspended solids. At this plant the operators had experienced considerable difficulty in their attempts to obtain adequate dewatering rates of the aerobically digested sludge by application to sand drying beds in depths of 8 to 10 inches. A complicating problem encountered in the operation of this facility was the continual presence of a thick layer of extremely stable, dark-brown, viscous foam on the mixed liquor surfaces of all units. This foam was usually 2 to 3 feet thick on the aerobic digester chamber and would occassionally overflow the tank, run down the side of the unit and cover large areas of ground. Even when the sludge was settled and the thickened underflow was removed and applied to the drying beds, foam formed on the dewacering sludge and undoubtedly inhibited evaporation of the free surface water. Similar problems were encountered in the pilot digester and model drying bed experiments. The height of the foam layer could usually be controlled to some extent by adjusting the rate of aeration, however, even when the aeration rate was maintained at a constant level, the foam would occassionally increase suddenly and overflow the unit. The foam could not be

TABLE IV

CONCENTRATIONS OF VARIOUS SLUDGES APPLIED TO BEDS

SLUDGE			TOTAL SOLIDS	VOLATILE SOLIDS
ORIGIN	RUN	DAY	MG/L	%
UNIVERSAL CITY	1	0	25,250	59.5
UNIVERSAL CITY	2	3	20,500	61.1
UNIVERSAL CITY	3	5	19,000	59.5
UNIVERSAL CITY	4	9	28,800	61.0
UNIVERSAL CITY	5	14	27,900	62.0
UNIVERSAL CITY	6	22	27,000	55.5
WCID NO. 16	1	0	18,200	57.5
WCID NO. 16	2	4	15,000	55.2
WCID NO. 16	3	15	15,300	56.6
THUNDERBIRD HILLS	1	0	19,300	61.7
THUNDERBIRD HILLS	2	4	20,250	62.0
THUNDERBIRD HILLS	3	15	25,000	60.0
KIRBY	1	0	18,350	60.5
KIRBY	2	8	16,600	57.8
OAK HILLS	1	0	18,450	60.0
OAK HILLS	2	4	19,550	57.3
OAK HILLS	3	15	19,500	58.3

dispersed by spraying and would not significantly subside even when aeration was discontinued for up to a 10 hour period.

The Thunderbird Hills facility, in general, was very poorly operated. It had a considerable odor problem, was very unsightly, produced a poor quality effluent, and the sludge in the aerobic digester was not well stabilized. By contrast, the Kirby, Oak Hills, and WCID No. 16 plants were well operated, produced good quality effluents, and the waste sludge was well digested. Each plant that had attempted sludge disposal on sand drying beds had experienced difficulty in obtaining adequate drying rates. Because of such difficulties encountered when the plant first began operating, at the time of this study digested sludge from the Kirby plant was disposed of by trench burial.

The characteristics of the aerobically digested sludges studied, when initially placed in the pilot digestion tanks, are listed in Table V. Of the parameters shown, the BOD of the mixed liquor best reflects the plant's operating conditions and the quality of effluent produced. Since the BOD of the mixed liquor is a measure of how well the sludge has been digested, it should also be related to the draining and dewatering properties of the sludge. The drainage rate of each sludge studied is compared to that of Salatrillo sludge in Fig. 17. As expected, the well digested sludges from Oak Hills and Kirby drained readily whereas the poorly conditioned sludges from Thunderbird Hills and Universal City drained at a considerably slower rate. Unexpectedly, however, the best digested sludge of the five as measured by mixed liquor BOD and per cent volatile matter, that from WCID No. 16, had the poorest draining rate. Furthermore, determination of total drainage time revealed that the anomalus WCID No. 16 sludge required 7 days to completely drain as compared to 4 days from the poorly digested sludges and a maximum of slightly more than one day for the well conditioned ones. These results are further compared to Salatrillo sludge data in Table VI along with the per cent of total applied water drained. It should be noted that, although the WCID No. 16 sludge required a longer drainage time, a larger percentage of the water was ultimately drained than for

TABLE V

CHARACTERISTICS OF VARIOUS AEROBICALLY DIGESTED SLUDGES

ANALYSIS	SLUDGE				
	OAK HILLS	KIRBY	WCID NO. 16	THUND. HILLS	UNIVERSAL CITY
TOTAL SOLIDS, MG/L	19,300	11,300	15,000	20,700	21,700
VOLATILE MATTER, %	61.5	58.5	56	65	60
MIXED LIQUOR BOD, MG/L	600	550	400	1,000	1,100
PH	6.4	7.4	6.6	6.0	6.7
CO_2, MG/L	12		8	20	28
NO_2, MG/L	0.05		0.062	0.25	0.09
NO_3, MG/L	19		15	26	7.5
NH_3, MG/L	0.25		0.25	0.25	1.25
ORTHOPHOSPHATE, MG/L	150		100	235	135
ALKALINITY, MG/L	70		80	60	130
SO_4, MG/L	100		160	150	300
CL^-, MG/L	90		120	110	80
SILICA, MG/L	80		95	130	70

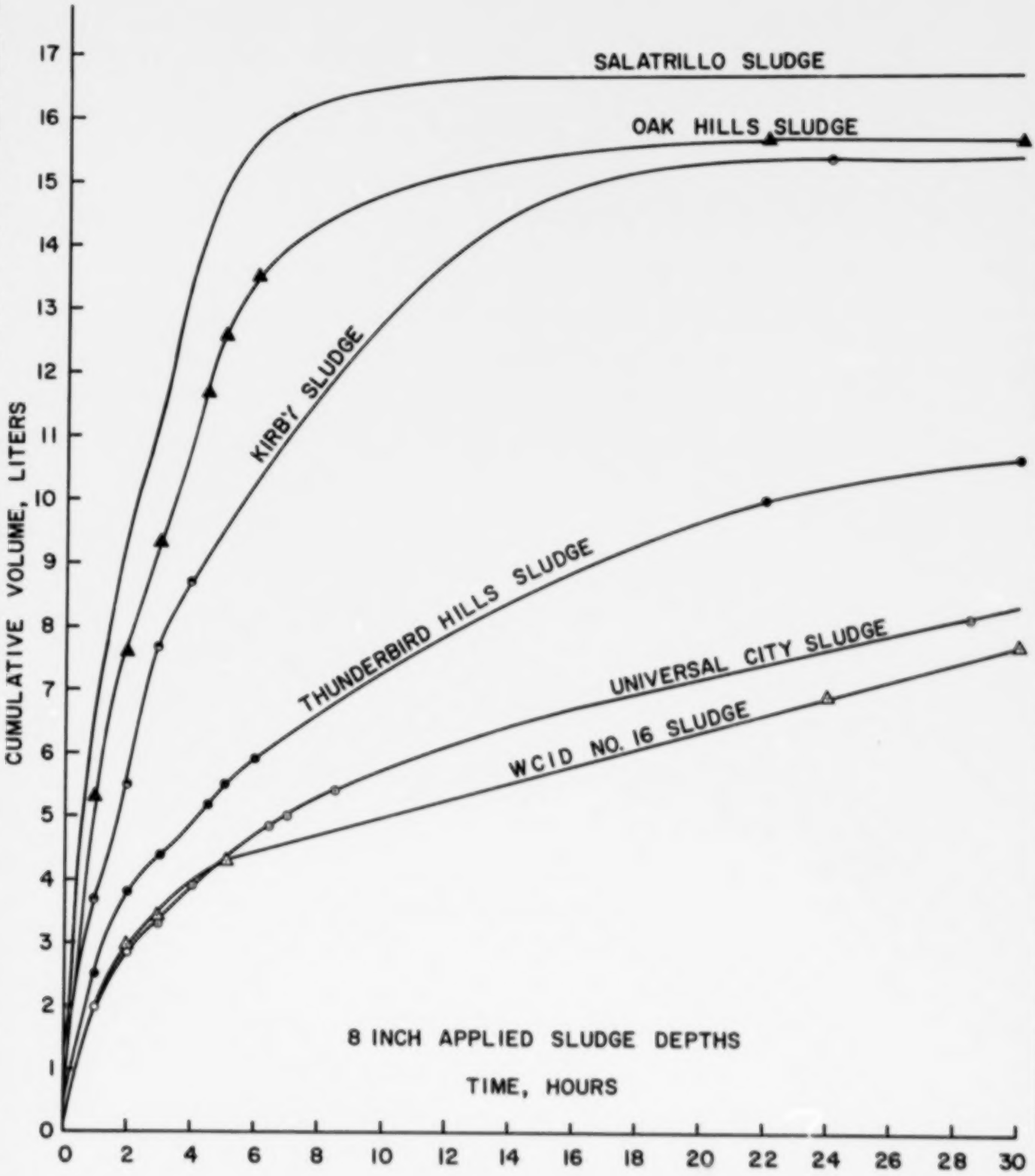


FIG. 17 COMPARISON OF SLUDGE DRAINAGE RATES

TABLE VI

COMPARISON OF TOTAL DRAINAGE AND DRAINAGE TIME

SLUDGE SOLIDS CONC. MG/L	APPLIED DEPTH (INCHES)	TOTAL WATER DRAINED AS PER CENT OF APPLIED VOLUME		TOTAL DRAINAGE TIME (DAYS)	
		COMPARED SLUDGE	SALATRILLO SLUDGE	COMPARED SLUDGE	SALATRILLO SLUDGE
		UNIVERSAL CITY SLUDGE			
25,250	8	55	72	4	0.29
25,250	6	66	78	3	0.21
25,250	4	63	74	2	0.13
		KIRBY SLUDGE			
18,350	8	73	80	1.3	0.33
		OAK HILLS SLUDGE			
18,450	8	72	80	0.4	0.33
		WCID NO. 16 SLUDGE			
18,200	8	60	80	7	0.33
		THUNDERBIRD HILLS SLUDGE			
19,300	8	72	75	4	0.29

Universal City sludge. The Universal City sludge contained considerable amounts of fiberous material which apparently had hygroscopic properties resulting in a large amount of retained water. A further note is that despite the long drainage time of the Thunderbird Hills sludge, the final drainage volume was virtually the same as that of the well conditioned sludges.

Microbial Interference of Drainage:

Since the WCID No. 16 sludge was the only test sludge whose relative drainage rate could not be reasonably predicted by the biological stability of the mixed liquor, the microscopic properties of the sludge were carefully studied and compared to other sludges to determine if any obvious abnormalities existed. Microscopic comparison revealed that the WCID No. 16 sludge contained large numbers of protozoa of the family Arcellidae which have a rigid, circular-sectioned, chitinous shell about 50 microns in diameter, organisms not found in any of the other sludges. Fig 18 is a microphotograph of some of these organisms as found in the digested activated sludge. The studies performed indicated that these microorganisms were numerous enough and that their effective size was such that they drastically reduced the drainage rate of the sludge by physically clogging the drainage pores of the sludge when it was placed on the drying beds. This hypothesis is supported by the fact that the WCID No. 16 sludge, once drained, dried as readily as the other well digested sludges.

Comparison of Drying Rates.

Using the data from the drainage experiments, the quality of water which had to be removed from each sludge by evaporation was calculated. The results, expressed in inches of water, are listed in Table VII. The calculations were based on final sludge cake moisture content of 15 per cent. It is of considerable interest to note that all of the sludges except that from Universal City and WCID No. 16 require virtually the same amount of moisture removal by evaporation. From reported studies of industrial sludges it has generally been

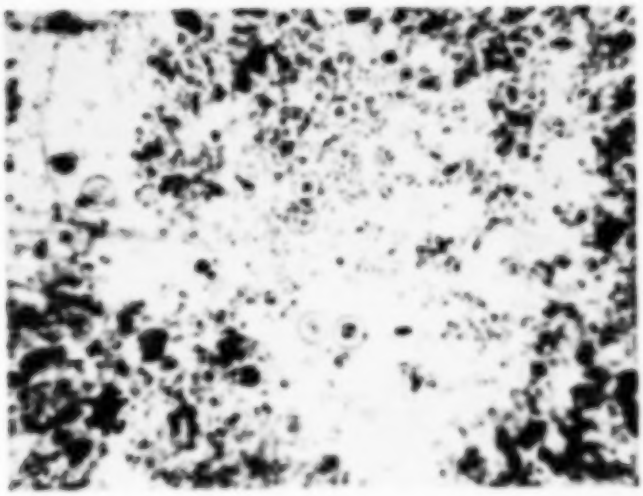


FIG. 18 MICROPHOTOGRAPH OF WCID NO. 16 SLUDGE
100 X

TABLE VII

INCHES OF WATER TO BE REMOVED BY EVAPORATION

SLUDGE ORIGIN	SOLIDS CONC. MG/L	PER CENT WATER DRAINED	REQUIRED EVAPORATION INCHES
UNIVERSAL CITY	25,250	55	3.8
KIRBY	18,350	73	2.4
OAK HILLS	18,450	72	2.4
WCID NO. 16	18,200	60	3.5
THUNDERBIRD HILLS	19,300	72	2.4
SALATRILLO	25,200	72	2.4
SALATRILLO	19,500	75	2.1
SALATRILLO	18,600	80	1.7

concluded that, although the rate of drainage of sludges may differ widely, the rates of evaporation are nearly the same. If this is true for aerobically digested activated sludge, the total time required for dewatering would depend primarily on the quantity of water than can not drain from the sludge, whether due to the hygroscopic properties of the material or because of physical hindrance. This would be true because, regardless of the total drainage time required, the time of sludge removal will finally depend on the evaporation rate, since the period of time required for drainage, typically the rate of drainage would have little significance whereas the total drainage volume would strongly influence the required dewatering time.

Dewatering rates of several sludges are shown in Fig.19. Since such data can be directly compared only if obtained under similar weather conditions, only the plotted values for Salatrillo sludge and Universal City sludge are exactly as observed. When those runs were conducted there was a complete absence of rainfall and the average free water surface evaporation rate was 0.45 inches per day. The plotted values for the other sludges were adjusted to simulate such conditions. Values for Oak Hill sludge were not plotted because of coincidence with other data points, however, dewatering times for all sludges along with the moisture content at the end of that period are listed in Table VIII.

The Thunderbird Hills, Oak Hills, and WCID No. 16 dewatering experiments were conducted simultaneously. Significantly, the Thunderbird Hills sludge dried as readily as Oak Hills sludge despite the considerable difference in drainage rate for the two sludges. Because of poor drainage, the WCID No. 16 sludge dewatered very little the first seven days, however, after that time, drying by evaporation occurred very rapidly. As expected, the Universal City sludge required the longest dewatering time. Besides evaporation hindrance from the foam layer on the free watersurface, when drainage was complete the sludge formed a tough, leathery surface which almost surely inhibited evaporation

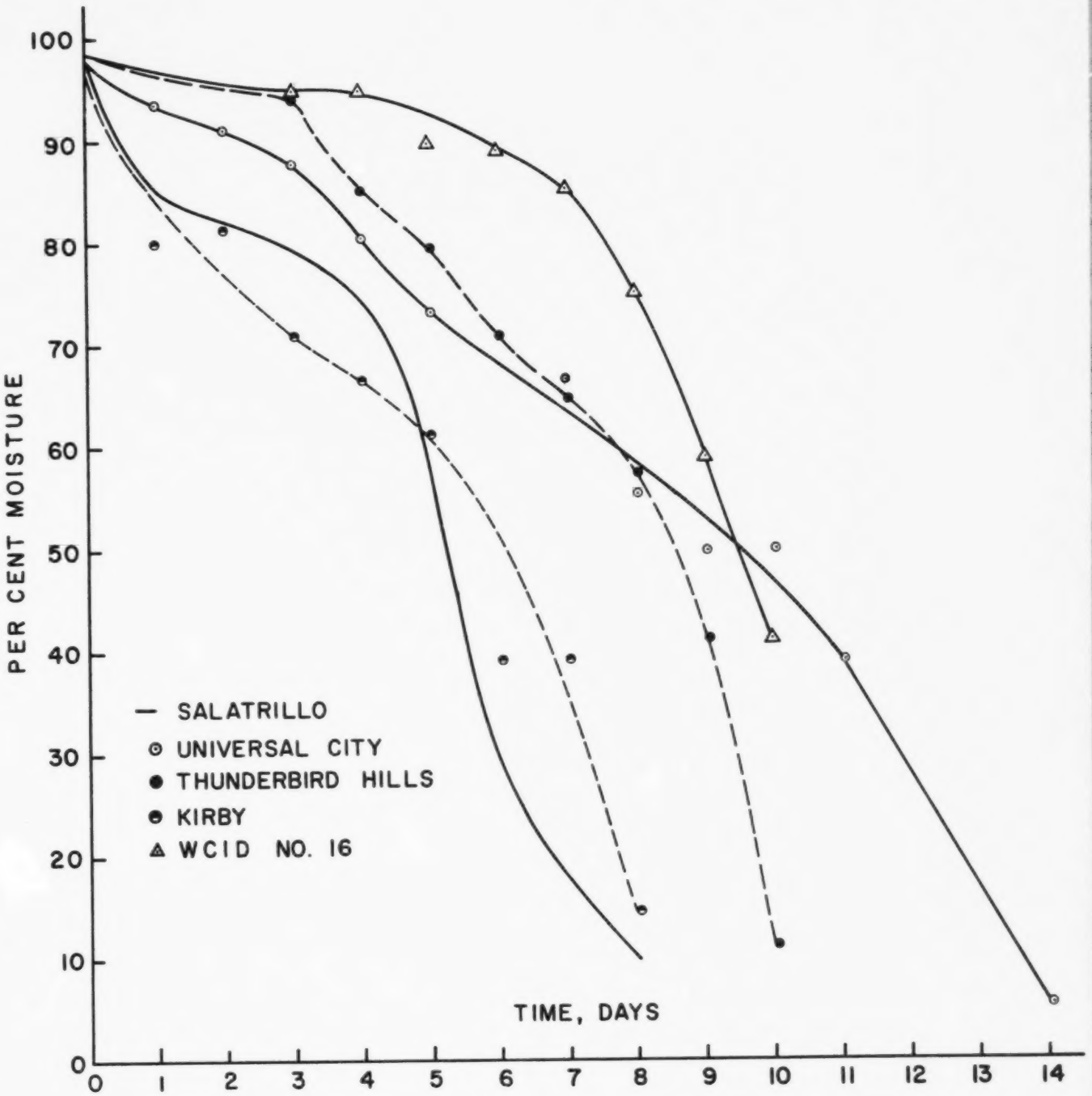


FIG. 19 COMPARISON OF SLUDGE DEWATERING RATES

TABLE VIII

COMPARISON OF ADJUSTED DEWATERING TIMES

SLUDGE ORIGIN	SOLIDS CONC. MG/L	TOTAL DRAINAGE TIME, DAYS	REQUIRED DRYING TIME, DAYS	FINAL MOISTURE CONTENT, %
UNIVERSAL CITY	25,250	4	14	6
THUNDERBIRD HILLS	19,300	4	10	11
WCID NO 16	18,200	7	10+	41
KIRBY	18,350	1.3	8	14
OAK HILLS	18,450	0.4	10	12
SALATRILLO	25,200	0.3	8	9
SALATRILLO	19,500	0.3	7	16

even further. This surface looked as if it had been spinkled with white powder. The interior of the Universal City sludge cake had a black, tarry, consistency and contained large amounts of fiberous material. The tendency of the material to hold water moisture is illustrated by the absence of a rapid decline in moisture content during the latter stages of the expirement as occurred with all other sludges. The Salatrillo and Kirby sludges dewatered very readily and here again the difference in drainage rate had little, if any effect on the total drying time. While the BOD of the mixed liquor has little, if any, effect on the moisture evaporation rate as illustrated by the Thuderbird Hills and Oak Hills results, aerobically digested activated sludges do vary in their tendency to hold moisture content as is evident from the three groupings obtained.

SLUDGE CONDITIONING EXPERIMENTS:

Extended digestion of the test sludges in the pilot digestion tanks caused considerable change in the mixed liquor and settled supernatnant characteristics. The data are summarized in Table IX. The samples represented were taken at the time intervals listed in Table IV. The data shows a progressive drop in mixed liquor BOD with length of digestion period indicating continued stabilization of the material. Considerable solids destruction also occurred. Unexpectedly, the percent of volatile matter in the sludge remained virtually constant throughout each experiment. This is contrary to what is reported in the literature; however, this same effect has also been noted by Wells (1) and Edde (2).

The drastic drop in pH that occurred in the units was disturbing. The Oak Hills, Thunderbird Hills, and WCID No. 16 units did not stabilize until after 12 days of extended digestion, and then the final pH values were so low that there was unquestionably inhibition of microbial processes. This inhibition is reflected by the large increase in orthophosphate concentration that occurred. The three units also had an increase in sulfate concentration in the supernatant and the Thunderbird Hills unit, which had a final pH of 4.5, had a considerable

TABLE IX

EXTENDED DIGESTION EFFECTS ON SLUDGE CHARACTERISTICS

CHARACTERISTIC	UNIVERSAL CITY					THUNDERBIRD HILLS			WCID NO. 16			OAK HILLS			KIRBY	
	RUN					RUN			RUN			RUN			RUN	
	1	2	3	4	5	1	2	3	1	2	3	1	2	3	1	2
TOTAL SOLIDS, MG/L	21,700	17,500	17,300	16,200	14,800	20,000	19,350	17,400	14,000	13,600	11,750	19,300	18,900	16,750	11,300	10,800
VOLATILE MATTER %	60	62	62.5	62.5	60	65	63	63.5	56	57	56.5	61.5	58	58	58	60
MIXED LIQUOR BOD, MG/L	1,100	1,005	950	460	330	1,000	950	615	400	350	300	600	500	460	550	350
-SUPERNATANT-																
PH	6.7	6.0	5.7	5.7	5.7	6.0	5.5	4.5	6.6	5.7	5.0	6.4	5.8	5.2	7.4	6.7
CO_2, MG/L	28	12	12	10	10	20	28	65	8	12	30	12	16	30		
NO_2, MG/L	.09	.25	.08	—	.03	.25	.10	.50	.06	.01	.05	.05	.10	.12		
NO_3, MG/L	7.5	30	40	—	55	26	34	90	25	24	40	19	30	60		
NH_3, MG/L	1.25	.50	.50	.40	.45	0.25	1.55	3.40	.25	.40	.30	.25	.30	.45		
PO_4, MG/L	135	138	140	150	150	235	390	675	100	190	300	150	170	300		
ALKALINITY MG/L	130	80	40	30	20	60	40	20	80	40	25	70	50	30		
SO_4, MG/L	300	300	300	300	300	150	140	230	160	170	195	100	130	160		
CL^-, MG/L	80	85	90	80	80	110	110	110	120	120	120	90	90	90		
SILICA, MG/L	70	65	75	68	75	130	130	130	95	95	95	80	80	80		

accumulation of ammonia nitrogen. By contrast, the Universal City unit's pH level stabilized after 5 days and never dropped below 5.7. Consequently, the orthophosphate concentration increased very little, the sulfate concentration not at all, and the ammonia nitrogen level stabilized after 2 days. The Kirby unit, on a comparative basis, had a very high pH value. However, the supernatant was never thoroughly analyzed.

As anticipated, extended digestion and the resulting additional stabilization of the sludges caused changes in the drainage and dewatering characteristics. Fig 20. illustrates some of the changes that occurred in the drainage rates. Additional information concerning the change in total drainage time and final volume drained is listed in Table X. The plot of the Universal City sludge data aptly illustrates that drainage from a poorly conditioned sludge can be dramatically improved by additional digestion up to a point, from a drainage standpoint further digestion then becomes self-defeating. The rate and total volume of drainage were considerably improved after 3 days of digestion and further improved after 5 days. However, after 9 days both parameters had lessened and after 14 days the rate was only slightly better than that initially observed. A similar effect occurred with the Thunderbird Hills sludge although the changes were smaller in magnitude.

Even though it was initially better-conditioned than the previously mentioned sludges, Kirby sludge showed a considerable improvement in both initial drainage rate and total volume drained after 8 days of extended digestion. However, total drainage time required increased. On the other hand, the initial drainage rate of the well-conditioned Oak Hills sludge steadily decreased with extended digestion while total drainage time increased. Neither the drainage rate nor the total volume of drainage from the WCID No. 16 sludge could be significantly changed by further digestion, however, the total period of time during which drainage occurred did drop from 7 to 5 days during the 15 day digestion period.

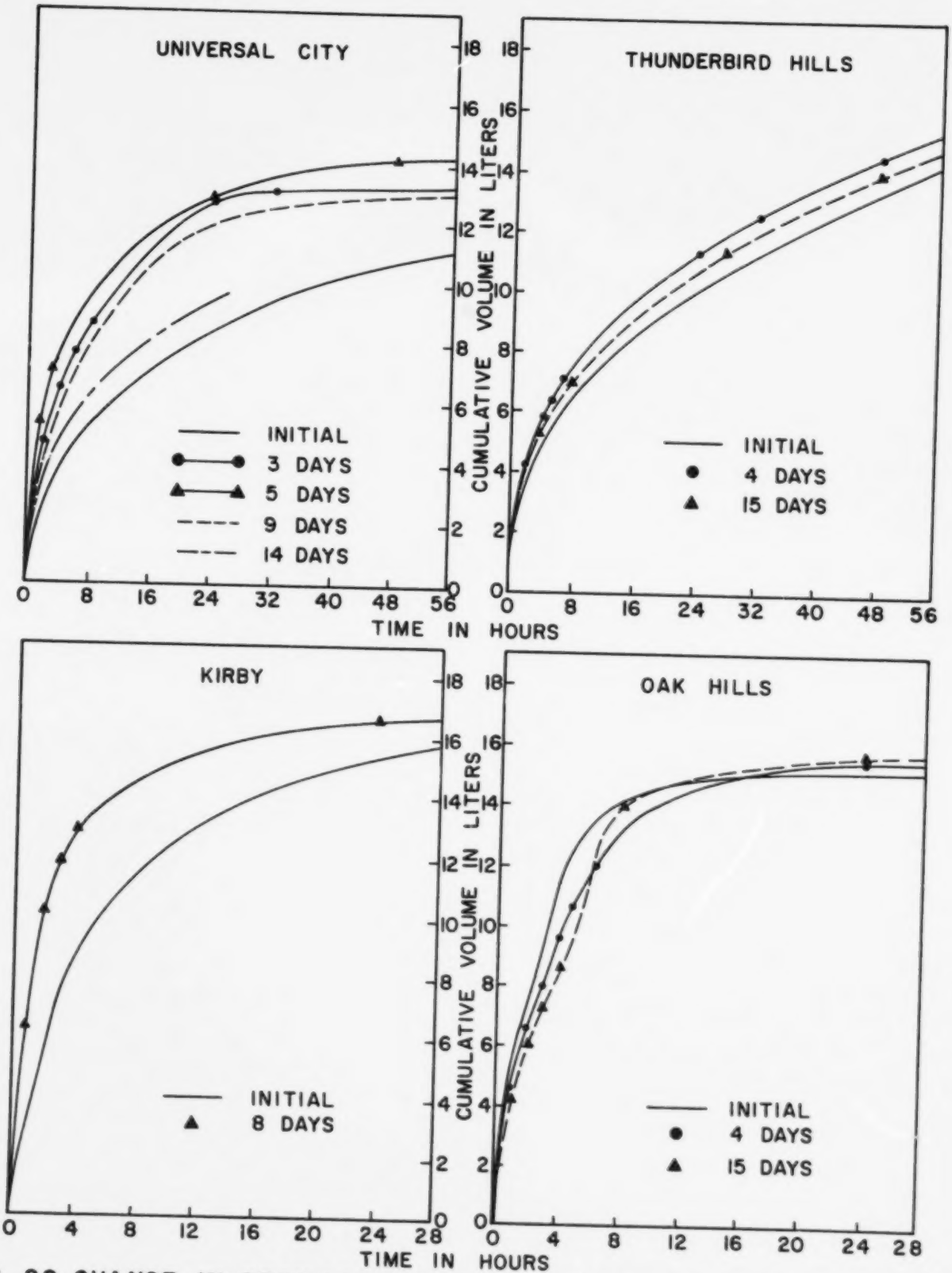
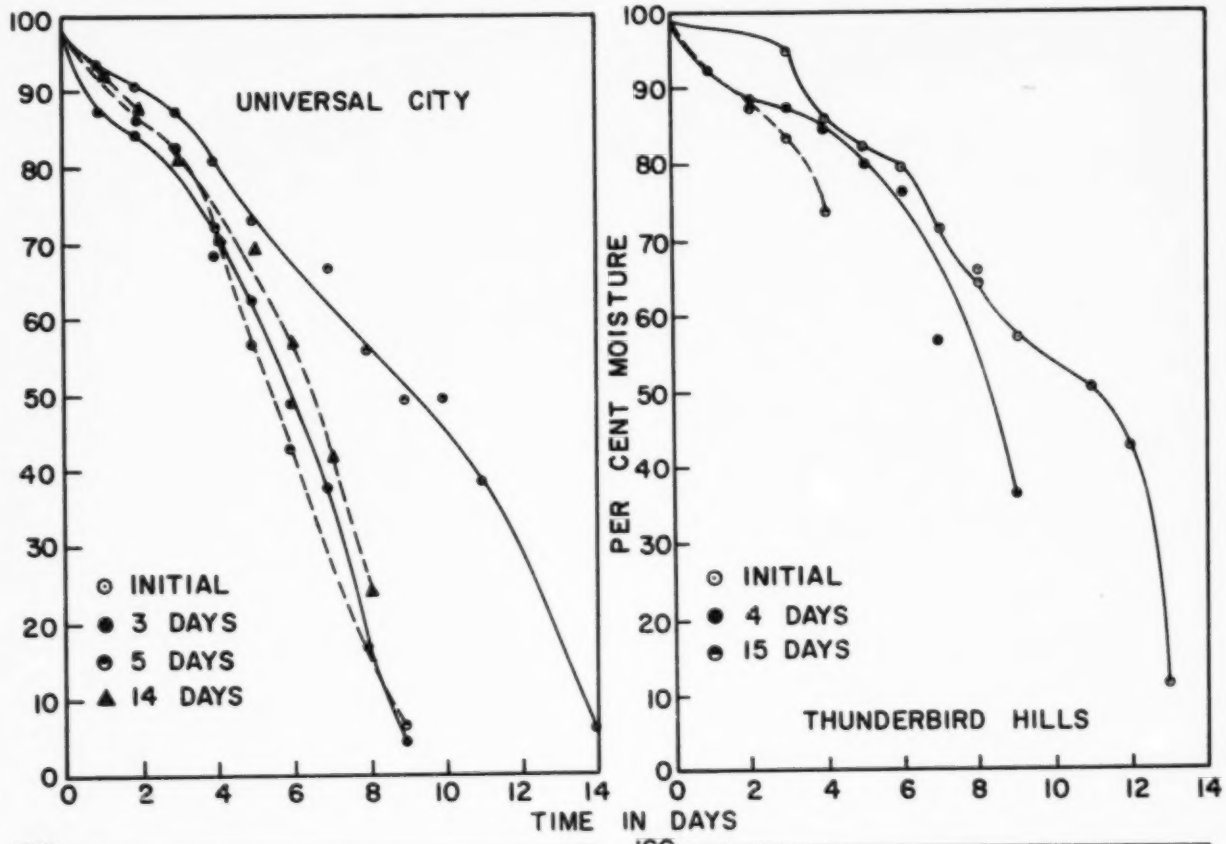


FIG. 20 CHANGE IN DRAINAGE RATES WITH EXTENDED DIGESTION

TABLE X

DRAINAGE TIME WITH EXTENDED DIGESTION

SLUDGE ORIGIN	APPLIED SOLIDS CONC. MG/L	APPLIED DEPTH INCHES	ADDITIONAL DIGESTION DAYS	DRAINAGE TIME DAYS	FINAL VOLUME %
UNIVERSAL CITY	25,250	8	0	4	55
UNIVERSAL CITY	25,250	6	0	3	66
UNIVERSAL CITY	25,250	4	0	2	63
UNIVERSAL CITY	20,500	8	3	1.33	62
UNIVERSAL CITY	20,500	4	3	0.33	72
UNIVERSAL CITY	19,000	8	5	2	67
UNIVERSAL CITY	28,800	8	9	2	62
UNIVERSAL CITY	28,800	4	9	1	64
THUNDERBIRD HILLS	19,300	8	0	4	72
THUNDERBIRD HILLS	20,250	8	4	3	72
THUNDERBIRD HILLS	25,000	8	15	2	66
WCID NO. 16	18,200	8	0	7	60
WCID NO. 16	15,000	8	4	6	60
WCID NO. 16	15,000	4	4	1.33	75
WCID NO. 16	15,300	8	15	5	61
KIRBY	18,350	8	0	1	73
KIRBY	16,600	8	8	2	79
OAK HILLS	18,450	8	0	1	72
OAK HILLS	19,550	8	4	1.33	74
OAK HILLS	19,500	8	15	1.33	74



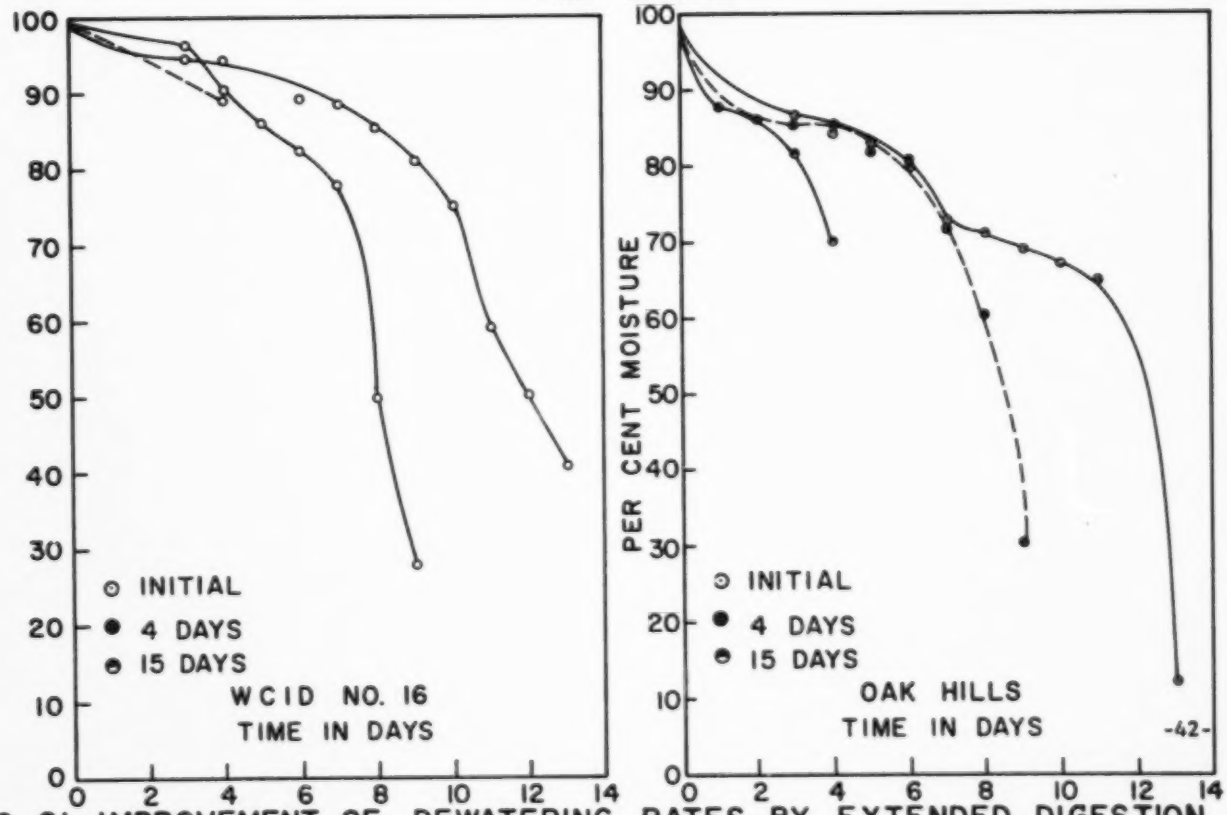


FIG. 21 IMPROVEMENT OF DEWATERING RATES BY EXTENDED DIGESTION

TABLE XI

CHANGE IN DEWATERING TIME WITH EXTENDED DIGESTION

SLUDGE ORIGIN	APPLIED SOLIDS MG/L	APPLIED DEPTH INCHES	EXTENDED DIGESTION PERIOD DAYS	DEWATERING TIME DAYS	FINAL MOISTURE CONT. %
UNIVERSAL CITY	25,250	8	0	14	6
UNIVERSAL CITY	25,250	6	0	10	7
UNIVERSAL CITY	25,250	4	0	7	8
UNIVERSAL CITY	20,500	8	3	9	4
UNIVERSAL CITY	20,500	4	3	5	10
UNIVERSAL CITY	19,000	8	5	9	6
UNIVERSAL CITY	28,800	8	9	8	12
UNIVERSAL CITY	28,800	4	9	5	8
UNIVERSAL CITY	27,900	8	14	8	24
THUNDERBIRD HILLS	19,300	8	0	13	11
THUNDERBIRD HILLS	20,250	8	4	9	36
WCID NO. 16	18,200	8	0	13	41
WCID NO. 16	15,000	8	4	9	28
WCID NO. 16	15,000	4	4	7	22
KIRBY	18,350	8	0	11	14
KIRBY	16,600	8	8	10	25
OAK HILLS	18,450	8	0	13	12
OAK HILLS	19,550	8	4	9	30

Change in Dewatering Properties:

The effect of extended digestion on the dewatering properties of the test sludges is summarized by the data given in Fig. 21 and Table XI. The purpose of the data as presented is to compare each sludge to itself rather than to each other. Therefore, it will be noted that, with the exception of the Universal City sludge, the initial dewatering times given are somewhat greater than the adjusted values previously discussed. The reason for this is that no attempt was made to adjust the values for evaporation rate if all experimental runs for the same sludge were conducted under similar conditions. Actually, the evaporation rate for all dewatering experiments except those with Universal City sludge was 0.24 inches per day. When the Universal City sludge experiments were conducted, the average evaporation rate was 0.45 inches per day as previously mentioned. The Thunderbird Hills, Oak Hills, and WCID No. 16 sludge tests were conducted simultaneously for each stage and are directly comparable. The Kirby sludge dewatering runs began a few days earlier than those three, but they overlap considerably and since the evaporation rate was the same, the data is regarded as directly comparable.

The data clearly illustrates that, for most of the sludges, additional digestion considerably reduced the length of time the sludge had to remain on the sand beds. As shown by the plotted values in Fig. 21, extended digestion progressively improved the dewatering properties of all sludges shown, except Universal City sludge, over a period of 15 days. The Universal City sludge was greatly improved by 3 additional days of digestion but continued digestion resulted in no further improvement. On the other hand, the dewatering properties of the Kirby sludge, not shown, remained virtually unchanged after 8 days of extended digestion. A similar occurrence had been observed previously with Salatrillo sludge.

RAINFALL EFFECTS: When necessary, the previously presented sludge drying data was adjusted for the prolonging effects of rainfall. While in several instances, particularly with Salatrillo sludge, the overall change in dewatering time was

particularly negligible, in other instances the required drying time on the sand beds was drastically increased. Such occurrences with the Universal City sludge, which contained a high percentage of hygroscopic fiberous material, were particularly noticable. The potential prolonging effect of rainfall is illustrated by Fig. 22.

Where dashed lines are shown in Fig. 22, rainfall occurred but no moisture determinations were made. Without rainfall, the sludge could have been removed from the sand bed after 8 days. Because of rainfall the required time was prolonged to 13 days, but, failure to remove the sludge before the 3rd rain extended the dewatering period to 19 days. An additional application of Universal City sludge with 14 days of extended digestion was made to the beds two days before the first rain listed and its dewatering time was increased from 9 to 18 days. Kirby sludge with no additional digestion was applied simultaneously resulting in a smaller increase of from 8 to 13 days.

The primary parameter with regard to the effect of rainfall on sludge drying is the amount of the rainwater that is retained by the sludge as contrasted to the amount that is readily drained. Such determinations were not made throughout the project but this data was collected in a few instances. Salatrillo sludge retained 42 per cent of the rain water following a 1.1 inch rainfall after 3-days on the sand beds. The same sludge retained only 27 per cent and drained 73 per cent of a 3 inch rainfall over a two day period when the rain began 10 days after the application to the beds. The second sludge had a solids concentration nearly twice that of the first. For the same 3 inch rainfall which began 3 days after the sludges were applied to the beds, Thunderbird Hills sludge retained only 15 per cent, Oak Hills sludge retained less than 27 per cent, and an 8 inch application of WCID No. 16 sludge retained 21 per cent while a 4 inch application retained only 18 per cent. All three of the sludges had been conditioned in the pilot digesters for 4 days.

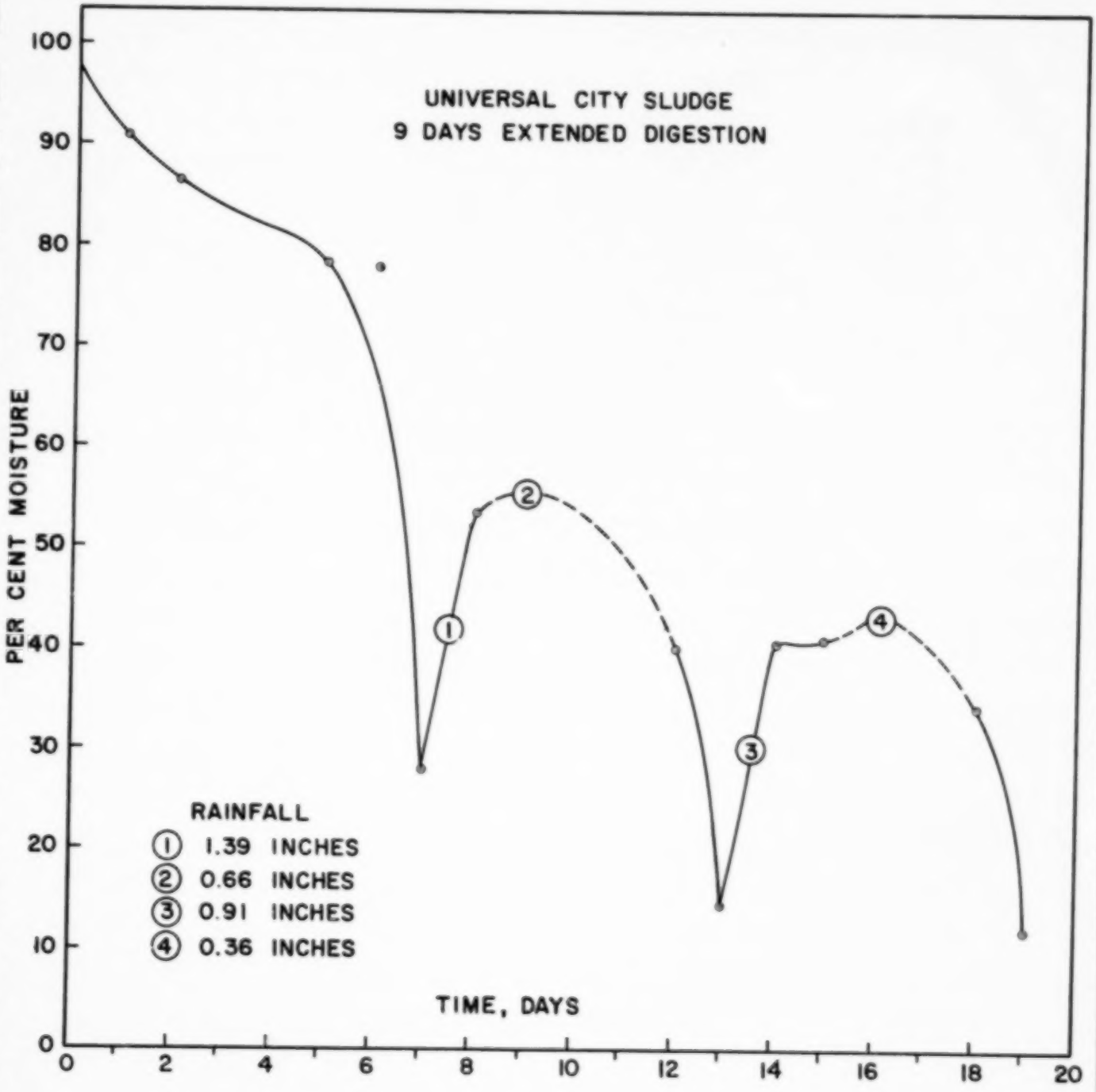


FIG. 22 PROLONGING EFFECT OF RAINFALL ON SLUDGE DRYING

Other investigators have attempted to assign values to the amount of rainfall that will drain through industrial sludges and the amount that will have to be removed by evaporation. The observations of this study indicate that such values for digested activated sludge are quite variable depending on the hygroscopic properties of the sludge and how soon after the sludge is applied to the beds rainfall occurs. With respect to the same sludge, it was repeatedly observed that a larger percentage of the rainwater drained if it occurred during the first 2 or 3 days after the sludge was applied than if it occurred after some of the bound water had been evaporated. With respect to different sludges, the ones studied during this investigation varied considerably in their tendency to retain water.

FILTRATE ANALYSIS During two experimental runs for each sludge studied, the filtrate from the model drying beds was analyzed and compared to an analysis of the settled supernatant in the pilot digesters. The tabulated results are shown in Table XII.

The most remarkable aspect of the comparison is the considerable reduction in orthophosphate concentration in the filtrate as compared to the settled supernatant. This significant reduction occurred in every experiment, and orthophosphate was the only parameter that was reduced in all cases. In fact, with the exception of carbon dioxide, the concentration of the other chemical compounds was typically greater in the filtrate than in the supernatant. Another significant change observed was a rather large increase in the pH value of the liquid following filtration. pH data was inadvertantly collected for only two of the sludge filtrates.

TABLE XII
FILTRATE ANALYSIS

ANALYSIS	SALATRILLO		UNIVERSAL CITY		WCID NO. 16		THUND. HILLS		OAK HILLS	
	SLUDGE ORIGIN									
(MG/L)	SUPER.	FILTRATE	SUPER.	FILTRATE	SUPER.	FILTRATE	SUPER.	FILTRATE	SUPER.	FILTRATE
	RUN NO. 1									
CO_2	4	4	28	4	8	4	24	4	12	4
NO_2	.18	.40	.09	.20	.06	2.5	.25	1.5	.05	1.25
NO_3	59	46	7.5	10	15	38	26	35	19	22
NH_3	.20	.55	1.25	8.25	.25	.06	.25	.25	.25	.20
PO_4	68	28	135	5	100	17.5	235	68	245	75
ALK.	50	70	180	140	80	70	60	100	70	90
SO_4	110	125	299	228	160	200	150	160	100	120
CL	80	65	80	100	120	—	110	—	90	—
SILICA	32	43	58	51	70	70	140	90	80	90
PH	6.8	7.5	6.7	8.2	6.6	—	5.7	—	6.4	—
	RUN NO. 2									
CO_2	4	4	12	8	12	4	28	12	16	8
NO_2	.34	1.35	.25	.58	.01	.08	.05	.18	.10	.28
NO_3	80	65	30	48	24	36	34	70	30	42
NH_3	.15	1.02	.50	0	.40	—	1.55	2.18	.30	.93
PO_4	53	20	137	38	190	20	390	65	400	65
ALK.	40	40	100	80	40	50	40	130	50	70
SO_4	135	112	300	300	170	180	140	250	130	160
CL	65	60	85	100	—	—	220	—	—	—
SILICA	44	45	62	65	95	60	115	25	75	90
PH	6.6	7.4	6.0	7.2	5.7	—	5.5	—	5.8	—

SUMMARY AND CONCLUSIONS

The data accumulated during this research project demonstrates primarily that sand bed drying of aerobically digested activated sludge is potentially an efficient method of disposal. However, it must be recognized that the open-air drying process is subject to many variables and that sludges from different plants may vary widely in their dewatering characteristics. It is difficult to use this method successfully unless the treatment plant is properly operated, the sludge beds have been adequately designed, and the properties of the digested sludge are known and understood.

The results establish that, for a well-conditioned sludge, drainage normally occurs very rapidly. Much faster than drainage from aerobically digested sludge. Unlike what Hamlin and El-Hattab (3) found with anaerobically digested sludge, however, rapid initial draining does not typically cause clogging of the lower layers. Such clogging can occur, though, with a sludge that contains large numbers of small, circular, rigid-shelled organisms. The parameter of greatest importance with regard to drainage is not the drainage rate, but the per cent of total water that is drainable. Here again, the per cent of drainable water in aerobically digested activated sludge is considerably greater than that reported for anaerobically digested sludge (4). This is particularly significant from a dewatering standpoint, because, with most sludges the time required for evaporation of moisture is considerably longer than that required for drainage. Therefore, the total time the sludge must remain on the bed is controlled by the amount of water that must be removed by evaporation. As a result, the amount that can be removed by drainage becomes extremely important, and the beds must be so designed that drainage is controlled by the sludge properties rather than by the underdrain system. This is aptly illustrated by the experiments comparing performance of paved beds with a centerdrain to regular sand beds. On the paved beds, water that could have been removed by drainage had to be removed by evaporation, thus, the required drying time was greatly prolonged.

From the experimental data obtained, if the sludge is well conditioned it is considerably more efficient to apply 8 inch depths of sludge to the beds than 4 inch or 6 inch depths. On the other hand, the operator should keep in mind that, if the sludge has poor dewatering properties, in some cases drying may be more efficient if thin layers are applied. Another operational parameter of considerable significance is the concentration of solids applied. As the solids concentration increases, the per cent of drainable water decreases. Nevertheless, the results show that, for a sludge with good dewatering properties, it is just as or more efficient to apply as heavy a concentration as possible. There may be some situations where the frequency of rainfall makes the application of small concentrations more desirable to minimize prolonging effects.

Considerable effort was expanded throughout the project in an attempt to determine a parameter that could be used to predict the dewatering characteristics of aerobically digested sludge. The basic idea was to develop a relatively simple test that could be performed by the operator to "measure" whether the sludge in the digester was sufficiently conditioned for application to the drying beds This task proved to be quite difficult, and, while several parameters were evaluated during the course of the study, none of them were entirely satisfactory for the purpose.

No correlation whatever could be established between dewatering properties and the settling characteristics of the sludges. Sludge volume index loses significance when applied to heavy solids concentrations and was useless for prediction purposes. From the data accumulated, covering a range of 47 to 65 per cent, correlation of per cent volatile solids to dewatering was inconsistent and of little value. None of the tests run on the supernatant proved to be of significance in this regard.

The results do indicate, though, that the dewatering properties of aerobically digested activated sludge are closely related to the oxygen

utilization characteristics of the sludge. Sludges obtained from digesters where the dissolved oxygen (D.O.) concentration was maintained at a low level (less than 1.0 mg/l) dewatered poorly. In addition, from experience with the pilot digester units it was observed that if it was difficult to maintain a D.O. level of 2.0 mg/l in the mixed liquor, the sludge drained poorly and dewatering was inferior. The experimental data shows clearly that drainage rate varies inversely with the mixed liquor BOD except when microbial clogging becomes a factor. Unfortunately, the correlation between mixed liquor BOD and the rate of drying was less consistent, and, while mixed liquor BOD was usually a good indicator it was not foolproof. Since drainage rate correlated so closely with mixed liquor BOD, obviously the same statements apply to it. Rather than drainage rate, the tests show that the required drying time was more closely related to the per cent of drainable water present. Nevertheless, sludges that had the same volume of drainable water were observed to have different drying times and, therefore, different evaporation rates. While the evaporation rate from Universal City sludge was affected by several factors, with other sludges the variation was most likely a function of the amount of hygroscopic material such as ploysaccharides contained in each sludge.

Previous investigators (5) have shown that specific resistance of activated sludge is increased by 1.) low waste retention time, 2.) low D.O. levels, 3.) low temperatures, and 4.) high waste BOD's. While the results of the study reported here indicate that at least three of these factors affecting dewatering adversely, other studies (3,6) have shown that specific resistance cannot be correlated with dewaterability. The two sludge properties that seem to reflect dewaterability most closely are the activity of the sludge as measured by respiration, and the quantity of material present that has a high affinity for moisture. Logically, a promising area of study should be the correlation of dehydrogenase enzyme activity, or polysaccharide content, or both, to dewaterability.

The pilot digester studies showed that a simple and highly successful way to improve the drainage and drying properties of aerobically digested activated sludge is to extend the digestion period. Of those studied, the only sludges that could not be markedly improved, Salatrillo and Kirby, were from well-operated, underloaded plants and already had excellent dewatering characteristics. It appears that most aerobic digesters, as operated, are overloaded if open-air drying of sludge is to be practiced. The digestion period should be extended with care, though, since some of the sludges studied reached a point where additional digestion did more harm than good.

Generally speaking, aerobically digested activated sludge will retain 25 per cent or less of the rain that falls on it. However, the per cent retained may be higher since it can vary considerably depending on the time during the drying period when rain occurs, and on the nature of the sludge itself. The dewatering time of a sludge containing hygroscopic fiberous material can be drastically prolonged by rainfall effects. It may prove to be more economical to dry such sludges on enclosed beds rather than in the open-air.

Orthophosphate is selectively removed from aerobically digested sludge supernatant by sand bed filtration. By contrast, most chemical constitutents and the pH value are increased.

Extensive aeration of most of the sludges resulted in a drastic drop of pH. Low values of pH were accompanied by increases in the concentrations of orthophosphate and ammonia nitrogen indicating toxic inhibition of the microorganisms. A particularly interesting observation was that during aerobic digestion a considerable reduction of total suspended solids and volative suspended solids could be accomplished while the per cent volatile suspended solids changed almost not at all.

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APPENDIX

TABLE I

SALATRILLO SLUDGE

CONCENTRATIONS OF APPLIED SLUDGES

Sludge	Total Solids, mg/l
1A	25,400
1B	28.800
1C	29,200
1D	28,750
2	18,600
3A	17,300
3B	20,450
4	25,400
5A	14,600
5B	24,100
5C	25,200
5D	7,550
5E	19,500
6A	29,700
6B	38,000
7A	21,300
7B	34,000
8	28,300

APPENDIX

TABLE II

SALATRILLO SLUDGE

SLUDGE DRAINAGE RATES

Run	Applied Depth (inches)	Drainage Rate, liters per hour per square foot									Ultimate drainage volume, in percentage of applied volume
		1st hr.	2nd	3rd	4th	5th	6th	7th	8th	9th	
1A	8	5.8	2 2	2.0	3.0	1.1	0.9	0.2	0.2		71.0
1A	6	5.6	3.4	2.2	0.8						77.8
1A	4	5.9	1.3	0.1							72.8
1B	8	5.9	2.0	2.0	2.1	1.1	0.9	0.2	0.2		70.5
1B	6	5.9	2.8	1.8	0.7	0.3	0.2				85.0
1B	4	6.0	1.7	0.1	0.1						86.3
1C	8	5.7	2.0	1.6	1.5	1.2	1.0	0.7	0.6	0.4	70.5
1C	6	5.0	2.1	2.2	2.0	0.5	0.1	0.15	0.15		82.1
1C	4	5.1	1.8	0.3							78.7
1D	8	5.6	2.0	2.2	2.2	1.0	0.8	0.2	0.2	0.1	73.4
1D	6	5.2	2.4	2.2	0.7	0.4	0.1				80.0
1D	4	5.7	1.3	0.1							77.7
2	8	6.7	2.8	1.9	2.0	1.4	0.8	0.5	0.3	0.2	80.3
2	6	6.3	3.0	1.5	1.2	0.2					85.5
2	4	6.7	1.1	0.1							85.4
3A	8	6.8	3.2	3.1	2.2	0.5	0.3	0.2			79.4
3A	6	6.7	3.3	2.0	0.5	0.3					92,2
3A	4	6.4	1.4	0.1							86.4
3B	8	6.8	3.4	2.8	2.0	0.6	0.5	0.1			78.0
3B	6	6.0	3.4	1.7	0.3	0.2	0.1				85.0
3B	4	6.2	1.0	0.1							80.0
4	8	5.5	2.4	2.3	1.6	1.3	0.9	0.2	0.3	0.1	71.0
4	6	5.3	3.0	1.8	0.4	0.2	0.1				77.8
4	4	5.3	1.2	0.2							72.8
5A	8	6.7	2.2	2.8	1.9	1.1	0.8	0.1			79.3
5A	4	6.7	0.5								77.6
5B	8	5.7	2.4	2.9	1.8	0.8	0.5	0.6			71.0
5B	4	5.7	1.1								78.3
5C	8	6.0	2.3	2.4	1.9	1.0	0.5	0.4			72.0
5C	4	5.5	1.2	0.1							74.0
5D	8	8.9	4.2	3.2	2.7						85.7
5E	8	6.9	3.1	1.8	1.0	1.4	1.0	0.3			74.5
5E	4	5.8	2.1								85.5
6A	8	5.0	2.0	2.3	1.9	1.4	0.8	0.4	0.2	0.2	70.5
6A	6	4.3	2.9	1.6	0.5	0.3	0.1				70.8
6A	4	5.0	1.9	0.1	0.1						77.5
6B	8	4.4	1.9	2.2	2.0	1.0	1.0	0.5	0.4	0.2	69.0
6B	6	4.2	2.3	2.0	0.8	0.2	0.2	0.1			71.8
6B	4	4.5	1.5	0.2							67.2
7A	8	6.7	4.1	2.2	0.5	0.3	0.2	0.1	0.1		73.6
7B	8	5.2	3 8	2.5	1.0	1.2	0.8	0.5	0.2	0.2	76.3
8	8	4.5	2.0	1.7	2.8	1.5	0.5	0.5	0.4	0.4	72.0

APPENDIX

Table III

SALATRILLO SLUDGE

VARIATION OF SLUDGE DEPTH

Run	Applied Depth, Inches	Measured Depth of Sludge, Inches															Final Moisture Content Per Cent
		1 hr.	2	3	4	5	6	7	8	17	1 day	2	3	4	5	6	7	
1A	8	5.75	4.75	3.9	2.5	2.0	1.75		1.75			1.50	1.20	1.20	1 20		1.10	12 9
1A	6	3.75	2.10	1.5	1.1	1.05	1.00		1.00		1.00	1.00	0.90	0.85	0.85		0.80	13 0
1A	4	1.75	1.10	1.0	1.0	1.0	1.0		1.0		0.80	0.75	0.60	0.60	0.55		0.40	8.7
1B	8	5.50	4.50	3.6	2.75	2 1	1 0		1.9		1.75	1.5	1.4	1.2			1.15	16.9
1B	6	3.75	2 50	1 5	1.25	1.1	1.1		1.1		1 1	1.1	1.1	1.1			0.90	18.9
1B	4	1.50	0.90	0.75	0 75	0.75	0.75		0 75		0 75	0.75	0.75	0.75			0.60	9.3
1C	8	5.75	4.90	4.1	3.4	2.75	2 15		2.00		1.75	1.7	1.6	1.55			1.20	30.0
1C	6	4 00	3.20	2.2	1.75	1.5	1.5		1.5		1.4	1.25	1.15	1.15			1.00	13 5
1C	4	2.00	1.10	1.0	1.0	0.95	0.95		0.95		0.9	0.75	0.75	0.75			0.50	8.8
1D	8	5.60	4.75	3.75	2.75	2.3	2.0		1.9		1.8	1.75	1.45	1.45			1.20	19.5
1D	6	3.85	2.30	1.8	1.5	1.5	1.35		1.35		1.35	1.25	1.00	1.0			0.90	9.4
1D	4	1.50	1.00	0.95	0.95	0.95	0.90		0.90		0.90	0.75	0.60	0.6			0.50	9.4
2	8	3.25	4.1	3.0		1.9	1.25			1.25		1.0		0.85				12.3
2	6	3.25	2.0	1.0		1.0	0.9			0.9		0.8		0.6				12.8
2	4	1.25	0.6	0.5		0.5	0.5			0.5		0.5		0.45				9.4
3A	8	5.00	3.6	2.5	1.5			1.1	1.1		1.0	0.9	0.8	0.75	0.75			10.2
3A	6	3.25	2.0	1.0	0.85			0.75	0.75		0.75	0.75	0.6	0.6	0.6			10.1
3A	4	1.25	0.6	0.55	0.55			0.55	0.55		0.55	0.5	0.45		0.45			9.8
3B	8	5.00	3.5	2.25	1.45		1.25		1.1		1.1	1.05	0.9	0.9	0.8			25.2
3B	6	3.50	2.0	1.2	1.0		1.0		1.0		1.0	0.8	0.8	0.7	0.65			32.1
3B	4	1.10	0.7	0.7	0.6		0.6		0.6		0.6	0.5	0.45		0.45			9.5

APPENDIX

TABLE III

SALATRILLO SLUDGE

VARIATION OF SLUDGE DEPTH

(Continued)

Run	Applied Depth, Inches	1 hr.	2	3	4	5	6	7	8	17	1 day	2	3	4	5	6	7	Final Moisture Content Per Cent
4	8	5.40	4.4	3.1	2.5	2.0	1.75	1.6	1.5		1.5	1.4	1.4			1.0		8.4
4	6	3.50	2.2	1.4	1.2	1.1	1.05	1.05	1.05		1.05	1.0	1.0			0.75		9.1
4	4	1.25	1.0	0.9	0.9	0.85	0.8	0.8	0.8		0.75	0.6	0.6			0.4		9.1
5A	8	5.0	3.6	2.5	1.7	0.85					0.85	0.85	0.75	0.6	0.4			4.5
5A	4	0.6	0.4	0.4	0.4	0.4					0.4	0.35	0.35	0.15	0.15			4.4
5B	8	5.45	4.4	3.1	2.25	1.6					1.5	1.25	1.25	1.0	0.8			10.8
5B	4	1.4	1.0	1.0	0.9	0.85					0.85	0.65	0.5	0.6	0.25			6.1
5C	8	5.3	4.3	3.25	2.25	1.65					1.5	1.5	1.25	1.15	1.1			8.4
5C	4	1.25	0.8	0.75	0.7	0.6					0.6	0.6	0.6	0.55	0.45			3.9
5D	8	4.5	2.2	1.4	0.6	0.4					0.4	0.35	0.25	0.15	0.15			5.0
5E	8	5.0	3.75	2.8	2.0	1.4					1.2	1.2	0.95	0.75	0.75			9.7
5E	4	1.1	0.6	0.6	0.6	0.5					0.5	0.5	0.45	0.45	0.25			5.0
6A	8	5.6	4.6	3.75	2.9			2.0	1.9		1.75	1.6	1.4'	1.5			0.8	7.5
6A	6	3.75	2.5	1.8	1.5			1.4	1.4		1.25	1.25	1.1	1.1			0.6	10.2
6A	4	1.85	1.0	1.0	0.8			0.8	0.8		0.8	0.7	0.7	0.5			0.45	7.2
6B	8	5.7	5.0	4.0	3.0	2.0			1.9		1.75	1.75	1.6	1.4			1.0	6.9
6B	6	3.75	2.75	1.8	1.55	1.25			1.25		1.25	1.20	1.1	0.9			0.65	9.3
6B	4	1.6	1.0	0.95	0.95	0.95			0.95		0.90	0.70	0.7	0.45			0.45	7.6
7A	8	3.2	2.8	1.8	1.5						1.5	1.1	0.95			0.95		24.0
7B	8	5.5	4.0	2.8							1.3	1.2	1.2			1.1		55.5
8	8	6.0	5.2	4.4	3.25	2.5	2.25				1.8	1.8						66.2

APPENDIX

TABLE IV

SALATRILLO SLUDGE

SLUDGE DEWATERING RATES

Run	Applied Depth (inches)	Solids Conc. (mg/l)	% Vol. Solids	Per Cent Moisture Variation with Time in Days										Amount and Time of Rain
				Start	1	2	3	4	5	6	7	8	9	10	
1A	8	25,400	46.7	97.4	85.2	82.9	78.5	78.0	73.9		58.6	45.5	12.9		1.1 inches between samples 3 & 4
A	6	25,400	46.7	97.4	84.6	82.8	81.0	79.2	75.9		50.7	13.0	11.6		
4A	4	24,400	46.7	97.4	80.6	76.1	74.0	73.2	66.6		13.6	10.1	8.7		
1B	8	28.800	45.0	97.0	82.2	79.5	78.2	76.5	76.7		61.4	42.7	16.9		
B	6	28,800	45.0	97.0	83.4	80.4	79.0	78.5	77.3		75.4	45.5	18.9		
4B	4	28,800	45.0	97.0	83.3	78.7	77.2	77.0	78.3		62.6	15.1	9.3		
1C	8	29,200	45.6	97.0	84.5	81.6	79.3	77.8	75.0		76.8	51.4	30.0		
C	6	29,200	45.6	97.0	84.4	82.0	78.2	[illegible]	77.5		69.2	40.4	13.5		
4C	4	29,200	45.6	97.0	83.9	76.7	77.0	[illegible]	70.5		55.4	10.0	8.8		
1D	8	28,750	46.6	97.0	84.6	80.2	78.8	77.8	71.4		67.0	54.1	19.5		
D	6	28,750	46.6	97.0	82.4	80.7	69.2	77.4	79.0		74.7	22.5	9.4		
4D	4	28,750	46.6	97.0	83.4	81.8	76.7	76.9	68.5		49.7	11.3	9.4		
2	8	18,600	48.1	98.3	85.0	81.0	78.2	78.8	73.0	70.5	52.3	12.3			1.2 inches between samples 3 & 4
	6	18,600	48.1	98.3	80.7	80.4	77.2	75.8	72.4	52.0	41.6	12.8			
4	4	18,600	48.1	98.3	77.3	77.5	72.4	72.5	65.0	48.4	9.4	8.8			
3A	8	17,300	46.7	98.4	84.3	81.5	78.9	68.3	66.3	16.9	10.2				1.2 inches before sample 1
A	6	17,300	46.7	98.4	77.7	81.9	79.7	70.2	63.4	16.1	10.1				
4A	4	17,300	46.7	98.4	70.9	82.6	79.7	71.0	52.0	10.1	9.8				
3B	8	20,450	48.4	98.2	82.4	81.9	78.9	73.5	67.9	37.4	25.2				
B	6	20,450	48.4	98.2	-	81.1	80.5	72.1	65.0	36.1	32.1				
3B	6	20,450	48.4	98.2	-	80.9	80.1	71.5	55.3	13.6	9.5				
4	8	25,400	46.1	97.4	84.2	81.8	83.3			75.4	62.9	39.3	16.9	8.4	
	6	25,400	46.1	97.4	83.6	89.9	79.7			73.4	62.6	25.2	14.9	9.1	
4	4	25,400	46.1	97.4		73.8	83.9			73.6	48.8	10.2	9.1	9.1	
5A	8	14,600	50.0	98.6	84.2	82.3	80.0	68.4	12.2	4.5					
A	4	14,600	50.0	98.6	83.6	82.0	61.7	11.8	4.4						
5B	8	24,100	50.0	97.5	84.5	81.0	79.2	73.8	34.2	30.7	20.4	10.8			
5B	4	24,100	50.0	97.5	83.9	82.4	79.0	66.6	6.1						
C	8	25,200	49.8	97.4	81.6	82.5	78.6	74.5	57.8	28.5	19.7	8.4			
5C	4	25,200	49.8	97.4	83.5	82.0	76.4	64.0	15.2	3.9					
5D	8	7,550	50.0	99.3	85.5	82.8	73.0	14.0	5.0						
E	8	19,500	50.0	98.0	84.3	82.5	79.2	73.8	58.6	41.7	16.2	9.7			
5E	4	19,500	50.0	98.0	83.9	78.3	76.1	62.2	5.0						
6A	8	29,700	49.1	97.2	86.0	82.9	81.0	78.0	-		47.1	35.0	18.4	7.5	
A	6	29,700	49.1	97.2	84.2	82.2	80.9	72.2	58.4		10.2				
6A	4	29,700	49.1	97.2	84.9	81.1	75.2	62.3	14.5		7.2				

APPENDIX

TABLE IV

SALATRILLO SLUDGE

SLUDGE DEWATERING RATES
(Continued)

Run	Applied Depth (inches)	Solids Conc. (mg/l)	% Vol Solids	Per Cent Moisture Variation with Time in Days											Amount and Time of Rain
				Start	1	2	3	4	5	6	7	8	9	10	
oB	8	38,000	48.4	96.1	84.0	81.4	80.5	68.7	76.3		29.6	17.2	8.0	6.9	
6B	6	38,000	48.4	96.1	83.5	80.6	78.1	69.1	67.7		9.3				
B	4	38,000	48.4	96.1	83.6	80.4	62.8	56.8	33.2		7.6				
A	8	21,300	45.3	97.4	83.7	84.8	83.6	-	-	24.0	62.0	65.1	45.1	30.5	0.3 inches between 7 & 8 after sample 10
7B	8	51,000	49.0	95.0	88.7	81.2	83.0	-	-	76.1	76.5	71.5	61.2	55.5	
	8	28,300	50.0	97.3	84.8	82.9	-	-	-	66.2	20.8	43.5	30.8		

APPENDIX

TABLE V

Salatrillo Creek Weather Data

Date	Temp. Range °F	Rel. Humd. Range %	Rain (inches)	Date	Temp. Range °F	Rel. Humd. Range %	Rain (inches)
July 1	74-98	93-33	0	August 6	75-100	85-29	0
2	72-92	91-43	0	7	73-100	85-30	0
3	75-96	90-33	0	8	76-100	85-25	0
4	75-97	82-28	0	9	77-101	79-29	0
5	78-98	82-28	0	10	76-101	85-28	0
6	78-100	82-26	0	11	80-93	72-23	0
7	75-100	85-22	0	12	68-93	59-20	0
8	75-98	87-27	0	13	62-92	52-17	0
9	74-100	87-27	0	14	63-94	70-22	0
10	72-100	87-23	0	15	64-95	81-32	0
11	76-98	85-28	0	16	67-95	84-32	0
12	77-98	85-29	0	17	70-98	93-35	1.39
13	71-98	100-36	.1	18	70-77	93-79	.09
14	71-93	97-32	1.2	19	73-83	93-74	.37
15	66-89	71-30	0	20	70-90	93-48	0
16	62-90	84-25	0	21	72-93	94-41	0
17	68-90	81-35	0	22	69-93	93-55	0
18	76-95	82-39	0	23	74-87	90-63	.91
19	78-96	82-34	0	24	72-86	93-59	0
20	73-87	94-65	0	25	69-93	97-45	.36
21	73-85	94-63	0	26	69-90	97-47	0
22	71-91	97-50	0	27	70-93	93-39	0
23	78-98	95-36	0	28	70-84	90-57	0
24	77-98	82-27	0	29	70-88	87-53	0
25	77-99	85-21	0	30	72-95	84-32	0
26	78-97	85-34	0	31	70-94	84-38	.3
27	78-99	79-31	0	Sept. 1	73-85	84-60	0
28	76-100	87-27	0	2	71-77	93-79	1.55
29	76-99	85-25	0	3	70-79	93-76	.48
30	76-100	85-26	0	4	69-85	93-61	.97
31	77-102	79-22	0	5	70-87	93-72	.04
Aug. 1	76-101	85-23	0	6	67-86	87-46	.11
2	77-99	85-32	0	7	66-87	87-43	0
3	76-101	88-35	0	8	68-88	84-41	0
4	75-100	87-27	0	9	64-90	87-35	0
5	70-98	87-29	0	10	65-88	81-39	0

APPENDIX
TABLE VI
TEST SLUDGES
SLUDGE DRAINAGE RATES

Run	Applied Depth (inches)	Drainage Rate Cumulative Total in Liters with Time																Ultimate Drainage volume, in percentage of applied volume
		1 hr.	2	3	4	5	6	7	8	9	1 day	1.33	2	3	4	5	6	7	
UNIVERSAL CITY SLUDGE																			
1	8	2.0	2.8	3.3	3.9			5.0	5.3	5.4			10.8	11.4	11.6				55.0
1	6	1.7	2.5	3.0	3.8			5.0	5.5				9.2	9.3					66.0
1	4	1.8	2.6	3.2	3.8			5.0	5.2				5.9						63.0
2	8	3.2	4.7	5.7	6.5	7.0	7.6	8.1	8.7		12.8	13.1							62.0
2	4	3.0	4.5	5.6	6.3	6.6	6.7	6.7	6.8										72.1
3	8	3.1	5.3	7.1							13.0		14.1	14.2					67.2
4	8	2.8	4.0	5.0	5.7	6.5	7.0				12.0		13.0						61.5
4	4	2.6	4.1	5.1	5.6	5.8	5.9				6.0								64.0
5	8	2.2	3.2	4.2	4.8						9.4		incomplete						--
6	8	5.0	7.5	8.8	9.5						15.4		15.8						74.5
WCID NO 16 SLUDGE																			
1	8	2.0	2.9	3.4		4.3	4.5				6.9			10.3	11.2	12.0	12.5	12.7	60.0
2	8	2.0	3.0	3.4	4.0	4.4		5.0			6.5	7.3	8.7	10.2			12.6		59.5
2	4	2.0	3.0	3.5	4.0	4.5		5.0			6.8	7.0							74.5
3	8	2.3	3.0	3.4	3.8				4.8		8.0		10.9	12.2	12.7	12.9			61.0
THUNDERBIRD HILLS SLUDGE																			
1	8	2.5	3.8	4.4		5.5	5.9				10.0			15.0	15.2				72.0
2	8	3.0	4.2	5.2	5.9	6.4	7.1				11.0	12.8	14.6	15.1					71.5
3	8	2.9	4.0	4.8	5.2				7.0		12.0		14.0						66.2
KIRBY SLUDGE																			
1	8	3.7	5.5	7.7	8.7						15.4								72.8
2	8	6.5	10.2	12.0	13.0						15.4		16.8						79.3
OAK HILLS SLUDGE																			
1	8	5.3	7.6	9.3	11.7	12.6	13.5				15.2								71.6
2	8	4.8	6.9	8.1	9.8	10.9	12.2				15.5	15.7							74.1
3	8	4.3	6.0	7.1	8.6				14.1		15.6	15.7							74.1

APPENDIX
TABLE VII
TEST SLUDGES
SLUDGE DEWATERING RATES

Run	Applied Depth (inches)	Total Solids (mg/l)	Per Cent Moisture Variation with Time in Days																		Amount of Rain (inches)
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
UNIVERSAL CITY SLUDGE																						
1	8	25,250	97.3	93.5	90.8	87.4	80.3	73.2		66.3	55.4	49.4	49.5	38.5			5.6					[1] 1.39
1	6	25,250	97.3	92.8	85.8	84.0	76.0	58.0		57.1	54.2	15.0	7.0									[2] 0.66
1	4	25,250	97.3	86 5	79.7	76.1	55.6	49 5		8.1												[3] 0.91
2	8	20,500	97.9	87 6	84.8		68.0	62.4	49.1	37.8	16.8	4.0										[4] 0.36
2	4	20,500	97.9	84.2	78.8		57.7	10.1														[5] 1.75
3	8	19,000	98.1		85.6	83.0	71.2	5.71	43.7			5.5								18	19	[6] 1.25
4	8	28,800	97.4	86.4				77 8	77.5	27.4	[1] 53.7				40.0	14.5	[3] 40.7	41.5	[4]	34.4	12.4	[7] 0.97
4	4	28,800	97.4	80 6				81.8	6.9													[8] 0.04
5	8	27,900	97.1	93.8	86.5	[1] 87 1	81.4	[2]			81.9	71.6	[3] 76.8	69.8	[4]		57.0	65.8	41.1	24.0		[9] hurricane
6	8	27,000	98.3	[3] 84.6	75.5	[4] 83.3			77.1	70.9	63.7	53.9	43.6	[5]	6	7	8	54.8	46.6	28.2	[9]	
UCID NO. 16 SLUDGE																						
1	8	18,200	98.3	•	•	94.8	94.7	80.4	89.6	88.6	5	6	7	8	85.4	81.4	75.0	59.0	50.0	41.0		
2	8	15,000	98.5	•	•	96.4	5	6	7	8	90.5	86.2	83.0	78.0	50.0	28.0	[9]					
2	4	15,000	98.5	86.7	81.0	72.2	5	6	7	8	75.1	63.1	22.0	[9]								
3	8	15,300	98.6	•	•	•	89.0	[9]														
THUNDERBIRD HILLS SLUDGE																						
1	8	19,300	98.2	•		94.8	85.3	81.7	79.2	70.7	5	6	7	8	64.4	57.0	41.0	50.0	42.0	11.0		
2	8	20,250	98.2	•	88.0	87.3	5	6	7	8	85.0	79.5	76.0	56.0	65.0	36.0	[9]					
3	8	25,000	97.4	92.0	87.0	84.0	73.0	[9]														

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APPENDIX
TABLE VII (CONTINUED)
TEST SLUDGES
SLUDGE DEWATERING RATES

Run	Applied Depth (inches)	Total Solids (mg/l)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Amount of Rain (inches)
										KIRBY SLUDGE												
1	8	18,350	98.5	80.0	81.1[1]	70.9	66.3[2]				61.1[3]	39.0	39.0	55.0		14.0						
2	8	16,600	98.5[3]	87.8	84.4[4]	84.8			67.3	74.8	60.5	41.1	43.8	[5]	[6]	[7]		46.4	25.2			
										OAK HILLS SLUDGE												
1	8	18,450	98.3			86.2	84.3	83.5	79.7	72.8	[5]	[6]	7	[8]	70.9	68.5	72.0	67.0	65.0	12.0		
2	8	19,550	98.2	82.6	85.6	86.3	[5]	[6]	[7]	[8]	85.0	82.3	80.0	72.0	60.0	30.0[9]						
3	8	19,500	98.1	88.0	86.0	82.0	70.0[9]															

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